TECHNICAL PUBLICATION 87-4

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DESALINATION

A VIABLE ALTERNATIVE FOR LOCAL GOVERNMENT WATER SUPPLY PLANNING IN SOUTH FLORIDA

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500 890 Produced on recycled paper.

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EXECUTIVE SUMMARY

The capability for producing fresh water by desalination, especially through the Reverse Osmosis Membrane process, has been greatly increased in a very short time in Florida. In 1967 there was only one 2.6 million gallon per day (MGD) desalt plant, but since 1984, Florida has been producing in excess of 40 MGD. Most of Florida's desalted water is used for domestic purposes.

The phenomenal industry growth of desalination is due to technological advances such as improved membrane technology, better pre-treatment techniques, and new anti-scaling agents. These developments have reduced significantly the cost of producing potable water from Reverse Osmosis (RO) plants from \$1.00-\$1.15 to \$0.50-\$0.60/1000 gallons. The costs, now comparable to conventional ones, do not include capital recovery costs, however.

Comparisons of water quality from the two sources indicate that the quality of desalted water exceeds the quality of conventionally treated water. Most Florida water suppliers use chlorine as a disinfectant. Chlorine, however, reacts with humus and humic acids found in south Florida waters to produce precursors of Trihelomethane (THM). The EPA requires that water containing THM above a certain threshold be given further treatment to comply with their drinking water standards. One common method used to reduce THM is an Activated Carbon process. This additional treatment increases the cost of conventional potable water production. Florida Utility managers have been experimenting with alternative methods to remove THM. An EPA study shows that RO successfully removes not only THM from drinking water, but also is effective in removing volatile organic and synthetic organic compounds as well. Further, reverse osmosis membranes can be added in small increments, as needed, to produce increased quantities of high quality water during critical periods. Comparative costs, and the ease of installing additional membranes to produce high quality water, has made RO attractive at water supply plants on Florida's west coast.

Southwest Florida has been the largest user of desalted water in the state. With our unprecedented population growth and limited fresh water availability, the use of the RO technique for production of large quantities of potable water is eminent. Recently, Florida east coast well fields have shown signs of stress associated with low water levels, and the problems of salt water intrusion. This stress is due to higher pumpage during dry months to meet increased fresh water demands. Florida's population now is the fourth largest in the nation. South Florida, therefore, will need even larger quantities of potable water to meet the increased demands. Further, quality and ecological considerations may preclude the surface storage water in Lake Okeechobee and the Water Conservation Areas from providing the additional quantities of water needed in the near future.

On the east coast, Palm Beach County Utility System Number Five is already using RO technology to supply some of its potable water. Indian River County, in the upper east coast area, is desalting more than 2MGD of water to meet their fresh water needs. There are several other small-scale RO plants scattered along the east coast of Florida.

Brackish water from the Floridan aquifer has not been used extensively in southeast Florida. It can be utilized to produce potable water to satisfy future demands, using desalination. In addition to strictly desalting brackish water, RO membranes have been successfully field tested for wastewater treatment.

California now desalts 5MGD of its wastewater using the membrane process. In south Florida, reclaimed water for non-potable uses can be processed using this technology. For example, RO removes almost 99 percent of total phosphate and 84 and 79 percent, respectively, of ammonia nitrogen and nitrate nitrogen from wastewater. This technology should be explored for the reduction of phosphorus and nitrogen compounds input to Lake Okeechobee.

Water hardness can also be adjusted with this membrane process, instead of using the conventional lime softening method, and has been tested on a small scale. Economic projections have shown the advantage of using this alternative. So far, no large-scale plant has been built for this purpose.

Return flows from irrigated land can also be treated in this manner. The worlds's largest desalt plant, located in Yuma, Arizona, is being designed to lower the salinity of agricultural return flows.

The total unit production cost of water from low pressure RO plants varies from \$0.98 at a 25MGD plant to \$1.32 at a 1MGD plant. This cost includes the capital recovery cost, thereby making the technology competitive with conventional methods of producing potable water for domestic and industrial use.

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INTRODUCTION

Production of fresh water from the sea or from brackish water sources by use of semi-permeable membranes is a relatively new concept. Commercial application of this new technology started some 25 years ago, and it now produces more than 50% of the desalted water worldwide. Energy costs, using this technology, were a major prohibitive factor in producing pure water, but recent advances have reduced these energy costs. New membranes can operate at half the pressure needed by the older membranes, and use of proper pre-treatment techniques has extended membrane life span. New anti-scaling chemicals have also been introduced. These new chemicals are less expensive and require lower dosages than those previously used. Combined, these advances in technology have all contributed to reducing the total water production cost using semi-permeable membranes.

Florida is one of the largest desalt water users in the United States. In Florida, the production of fresh water by use of desalination started in 1967. The first 2.6 million gallons a day (MGD) sea water distillation plant was installed in the Keys. Since then, desalt plant installation has grown; by 1984 Florida had a desalting capacity in excess of 40 MGD. The majority of desalination plants in Florida are Reverse Osmosis (RO) plants which use brackish water as feed water.

In Florida, the basic reason for desalting water was to minimize transportation costs from inland areas. The city of Cape Coral is a prime example. This was especially true for small utility companies who required less than 5 million gallons of potable water a day. Recently however, even larger utility companies such as Boynton Beach and Fort Lauderdale are evaluating this alternative for their future water supplies.

Invention of low pressure membranes and availability of brackish water near demand points has made Reverse Osmosis very attractive to utility managers. Additionally, this technology also provides ease of installation of plants within a short time frame for additional drinking water.

Desalting in Florida, especially the membrane process of desalting, is likely to increase in the future. Florida's current population is in excess of 11 million. Forecasters predict the state will be the fourth largest state in the nation by the turn of the century.

To meet the potable demand for such an increase in population, Florida needs additional quantities of fresh water; however, fresh water supplies are limited in the southern portion of the state.

Due to water quality requirements and environmental and economic considerations, surface stored water from Lake Okeechobee and the Water Conservations Areas may not be able to meet the additional demands.

Recognizing the supply problems, the 1984 Florida Comprehensive Plan set forth policies on promoting and developing desalination. Newly elected Governor Martinez wants to explore desalination as an option of future water supplies of Florida (Tallahassee Democrat, Saturday, November 22, 1986).

The South Florida Water Management District is the regional water management agency for the area. One of the main functions of the District is to provide water resource related assistance to local governments. The District provides technical assistance in water supply planning, including desalination.

This report provides current information on membrane technology to water planners, engineers, and decision makers who are facing water supply problems. It addresses desalination and its growth in south Florida, and advances made to date in membrane technology.

The report also discusses potential applications of membrane technology to various other water resource problems facing south Florida today. Finally, the report concludes with a cost comparison of producing water by conventional methods, as well as with high and low pressure membranes.

DESALINATION

Desalination, as the name implies, is a process to separate a saline solution into pure fresh water and concentrated brine. Drinking water suppliers have been the predominant users of desalted water so far. However, provided the cost is not excessive, this water may be put to many uses. Agricultural irrigation could be one of the potential prime uses.

There are various methods of desalination which require input of energy in different forms such as thermal, mechanical, electrical, or chemical. Each method requires a minimum amount of energy to produce a given percentage of fresh water from saline supplies. Minimum energy required to separate 2000 gallons of sea water into 1000 gallons of fresh water and concentrated brine is 4.5 KWH (8).

Commercial desalination processes now in use are those that either remove water from solution or remove salt from solution. Electrodialysis and Ion exchange belong to the category that remove salt from saline solution. Reverse osmosis (RO) and Distillation remove water from solution (Figure 1).

Reverse Osmosis and Distillation processes are curently producing in excess of 90 percent of desalted water world wide. However, more Reverse Osmosis plants are being installed world-wide, as these plants take a shorter time to build than Distillation plants.

Following is a brief description of all currently available commercial desalination processes.

ELECTRODIALYSIS

Electrodialysis (ED) is an electrochemical process where ions pass through semipermeable membranes from a less concentrated to a saturated solution. Disassociation of salts, minerals, alkalies, and salt in water produces cation and anions. For example, sodium chloride (common salt) disassociates into sodium and chloride ions in water. Ions conduct electricity through the solution. The conductance of an electrolytic solution depends upon the concentration of ions, the ionic species, and the temperature of the solution. The ED process removes ions from water, thereby leaving almost pure quality water (Figure 2). Desalting water using electrodialysis requires membranes placed alternatively between the electrodes. These membranes allow either cations or anions to pass through them (Figure 2).

When an electric current passes through these electrodes they are charged. These charged electrodes drive the anions from the main product stream. The anions then pass through the anion selective membrane into the brine cell. Cation selective membrane prevents anions from moving through the adjacent cell wall. In the same way, cations move from the dilute stream on the other side of the cation selective membrane into the concentrate cell. Anion selective membrane prevents these from moving further towards the negative electrode. With this arrangement, concentrated and fresh water solutions form in the spaces between alternating membranes.

Cells are the spaces bounded by two membranes. A cell pair consists of two cells, one from which the ions migrate and the other in which the ions concentrate. In actual operation feed water passes simultaneously in parallel paths through all the cells. This provides a continuous flow of water and brine stream, thus washing out the concentrated brine.

The basic ED stack consists of an inlet feed channel, semi-permeable membranes and two electrodes. Each electrode connects to a source of direct current (Figure 3). A typical stack consists of several hundred cell pairs. The extent to which the feed water is desalted depends on the residence time within the stack and the applied current.

A single ED stack can remove from 25 to 60 percent of the feedwater's total dissolved solids depending

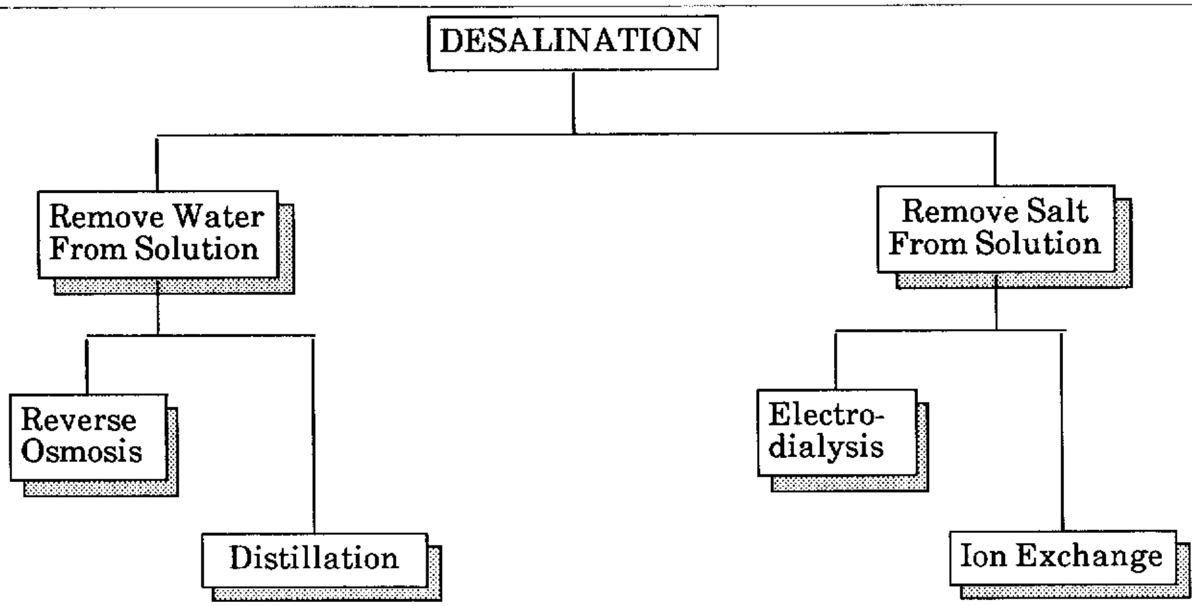
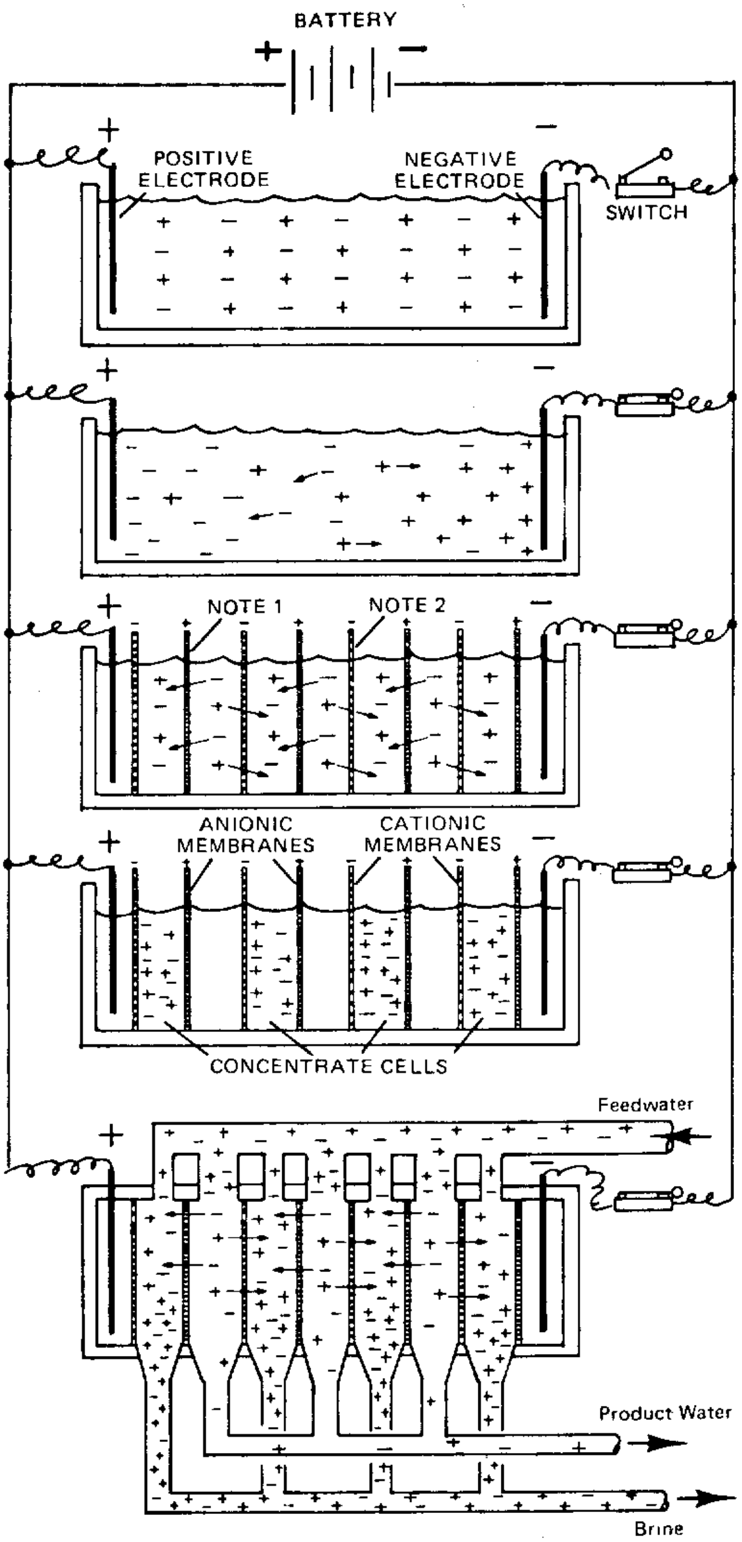


FIGURE 1. COMMERCIAL DESALINATION PROCESSES



Many of the substances which make up the total dissolved solids in brackish water are strong electrolytes. When dissolved in water they ionize; that is, the compounds dissociate into ions which carry an electric charge. Typical of the ions in brackish water are Cl^{-1}, Na^{+1}, HCO_3^{-1}, Mg^{+2}, SO_4^{-2}, and Ca^{+2}. These ions tend to attract the dipolar water molecules and to be diffused in times, fairly evenly throughout a solution.

If two electrodes are placed in a solution of ions, and energized by a battery or other direct current source, the current is carried through the solution by the charged particles and the ions tend to migrate to the electrode of the opposite charge.

If alternately fixed charged membranes (which are selectively permeable to ions of the opposite charge) are placed in the path of the migrating ions, the ions will be trapped between the alternate cells formed.

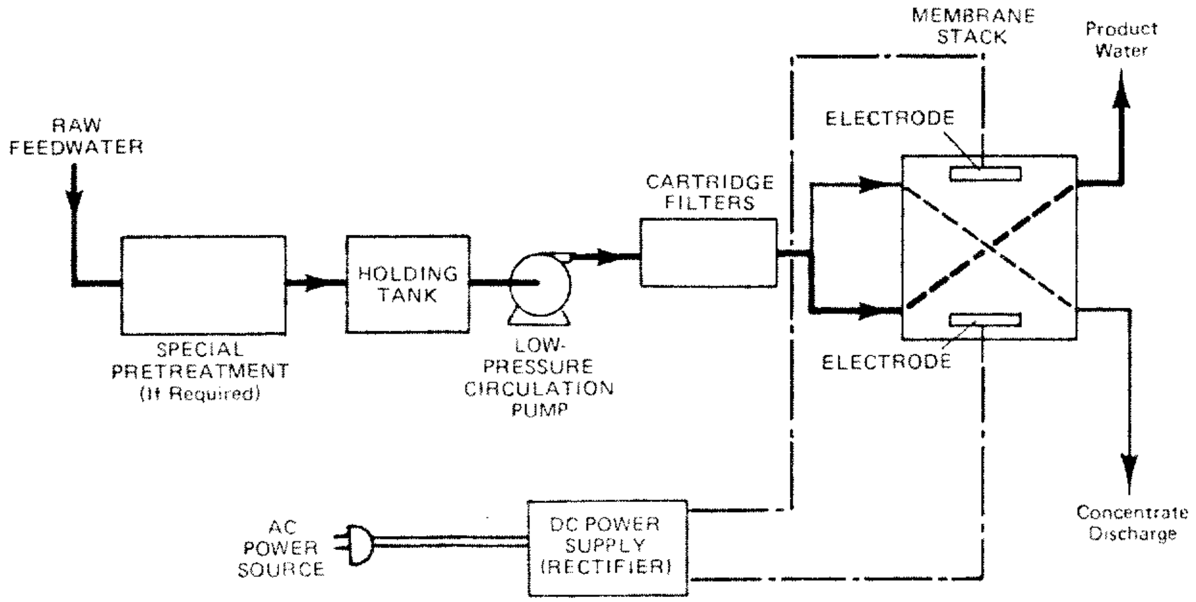
Note 1: A positively fixed charge (anionic) membrane will allow negative ions to pass, but will repel positive ions.

Note 2: A negatively fixed charge (cationic) membrane will allow positive ions to pass, but will repel negative ions.

If this continued, almost all the ions would become trapped in the alternate cells (concentrate cells). The other cells, which lack ions, would have a lower level of dissolved constituents and would have a high resistance to current flow.

The phenomenon illustrated above is used in electrodialysis to remove ions from incoming saline water on a continuous basis. Feedwater enters both the concentrate and product cells. Up to about half of the ions in the product cells migrate and are trapped in the concentrate cells. Two streams emerge from the device: one of concentrated brine and the other with a much lower concentration of TDS (product water).

FIGURE 2. MOVEMENT OF IONS IN THE ELECTRODIALYSIS PROCESS



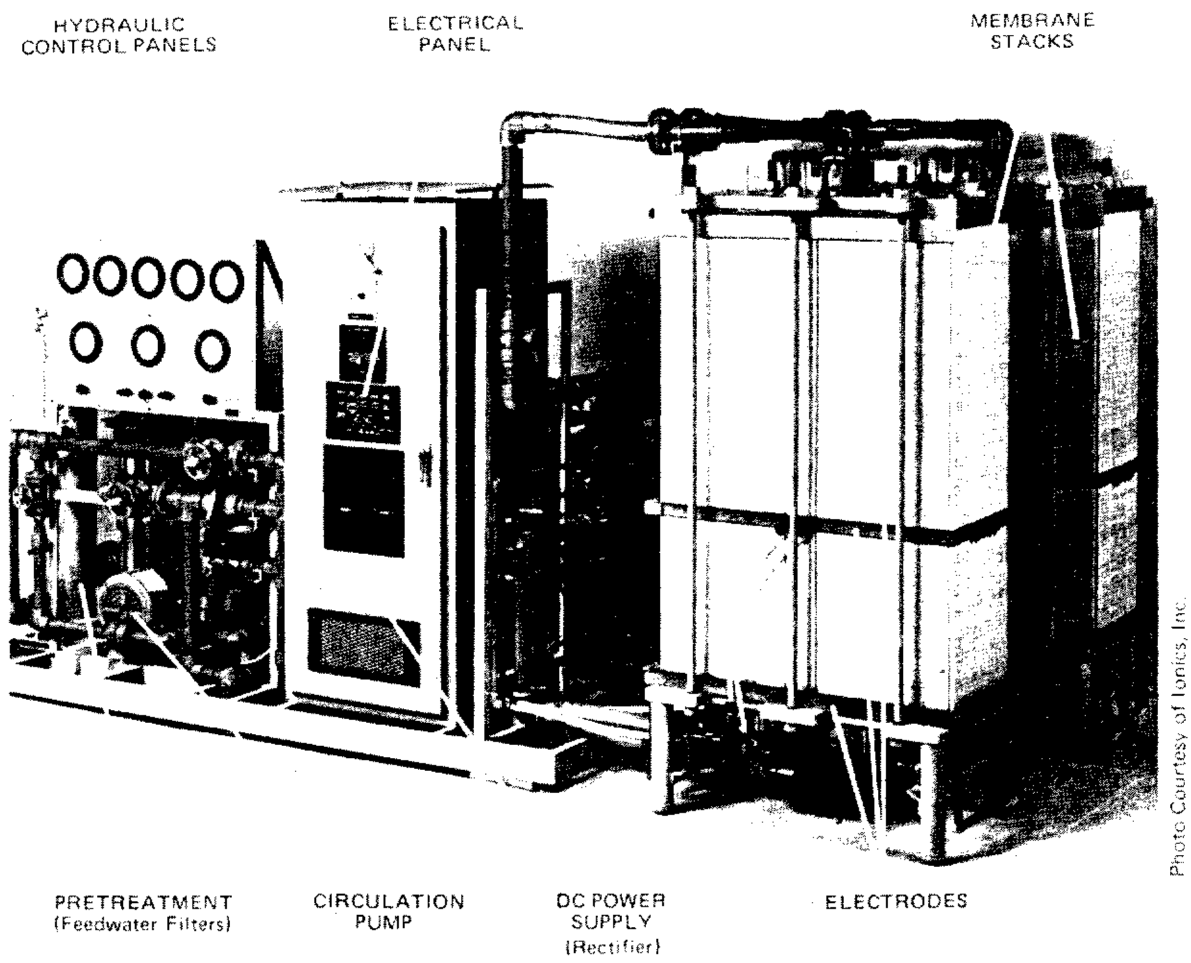


FIGURE 3. BASIC COMPONENTS OF AN ELECTRODIALYSIS UNIT

on feed water concentrations. Further, ED desalting requires two or more stacks in series. Staging is the manner in which the membranes stack array is arranged. Staging provides enough membrane area and retention time to remove a specified fraction of salt concentration from the demineralized stream. The actual selection and the number of stages required depends on the feed water composition and the desired product water quality.

Continuous operation of an ED plant generates fouling and scale deposit on the membrane surfaces. This results in an increase in stack resistance and power requirements. Pretreatment of the feed water is therefore necessary. In addition, periodic cleaning of the members extend the membrane lifespan.

The EDR (Electrodialysis Reversal) system now in use produces purified water on a continuous basis. Basically, the EDR process uses electrical polarity reversal to continually control membrane scaling and fouling. Polarity of the electrodes reverses three or four times each hour. This reverses the direction of ion movement within the membrane stack, thus controlling film and scale formation.

The EDR system demineralizes water without constant chemical addition during normal operation. EDR also eliminates the major problems faced by the previous ED system.

The energy (power) requirements of an EDR process (to desalt 1000 gallons of product water) for various feed water concentrations, as reported by DSS engineers (5), is as follows.

Feed Water, TDS	1500	2500	3500
ElectricityKwh/Kgal	6	9	12

The EDR process has the advantage of low energy requirements over other desalination processes for low TDS water. The energy requirement of the EDR process is directly proportional to the TDS removed. A booklet published by Ionics, Inc., provides a thorough description of Electrodialysis and Electrodialysis Reversal (10).

ION EXCHANGE

The ion exchange process consists of a chemical reaction between ions in a liquid and a solid phase. Certain ions in the solution are adsorbed by the ion exchanger solids. Later, due to electroneutrality maintenance in the process, the exchanger solid releases replacement ions back into the solution(18).

Industries use Ion Exchange for water polishing, as they require pure water for their processing. Home water with low salinities also use Ion Exchange softening. For home uses, ion exchange softens the calcium and magnesium enriched hard water. In this softening process sodium ions exchange calcium and magnesium ions.

The first commercially used ion exchange materials were naturally occurring porous sands, commercially known as zeolites. In recent years, synthetic organic exchangers have replaced the natural ones. These synthetic resin exchangers are better and have more ion exchange capacity than zeolites and are available for both cation and anion exchange (18).

Figure 4 presents schematics of equipment required for a fixed bed column for water softening with a sodium charged exchange resin. During the water softening cycle, water enters the top of the bed and flows downward. Once the allowable break-through of hardness occurs in the effluent, the controller activates the backwashing to remove any suspended material.

These suspended materials may have accumulated by filtering action during the softening cycle. After backwashing, the 5 to 10 percent salt solution passes through the exchanger at a controlled rate to regenerate the resins. Once regeneration is complete, a slow rinse flow passes through the bed to dilute the remaining regenerate solution to waste. A fast, short rinse cycle follows to remove the last traces of the regenerate solution from the bed. Once the fast rinse is complete, the column repacks on-line to continue the softening process (18).

DISTILLATION

Distillation is a process based on evaporation, the product being a volatile component. The theory of distillation is not new. Alchemists, chemists, and others have used this process to separate alcohol from water. Saline water converts to water vapor and dissolved salts when boiled. These salts, which are non-volatile, remain in the solution as water is vaporized. When cooled the vaporized water turns into pure water. The basic equipment used in distillation is an evaporator. An evaporator is a vessel containing the bulk of feed-water. Steam supplies the required latent heat through the evaporator tubes. The process requires large heat transfer surfaces for efficient use of the thermal energy. Saline water or brine feed used as a cooling medium in the condenser recovers much of the energy.

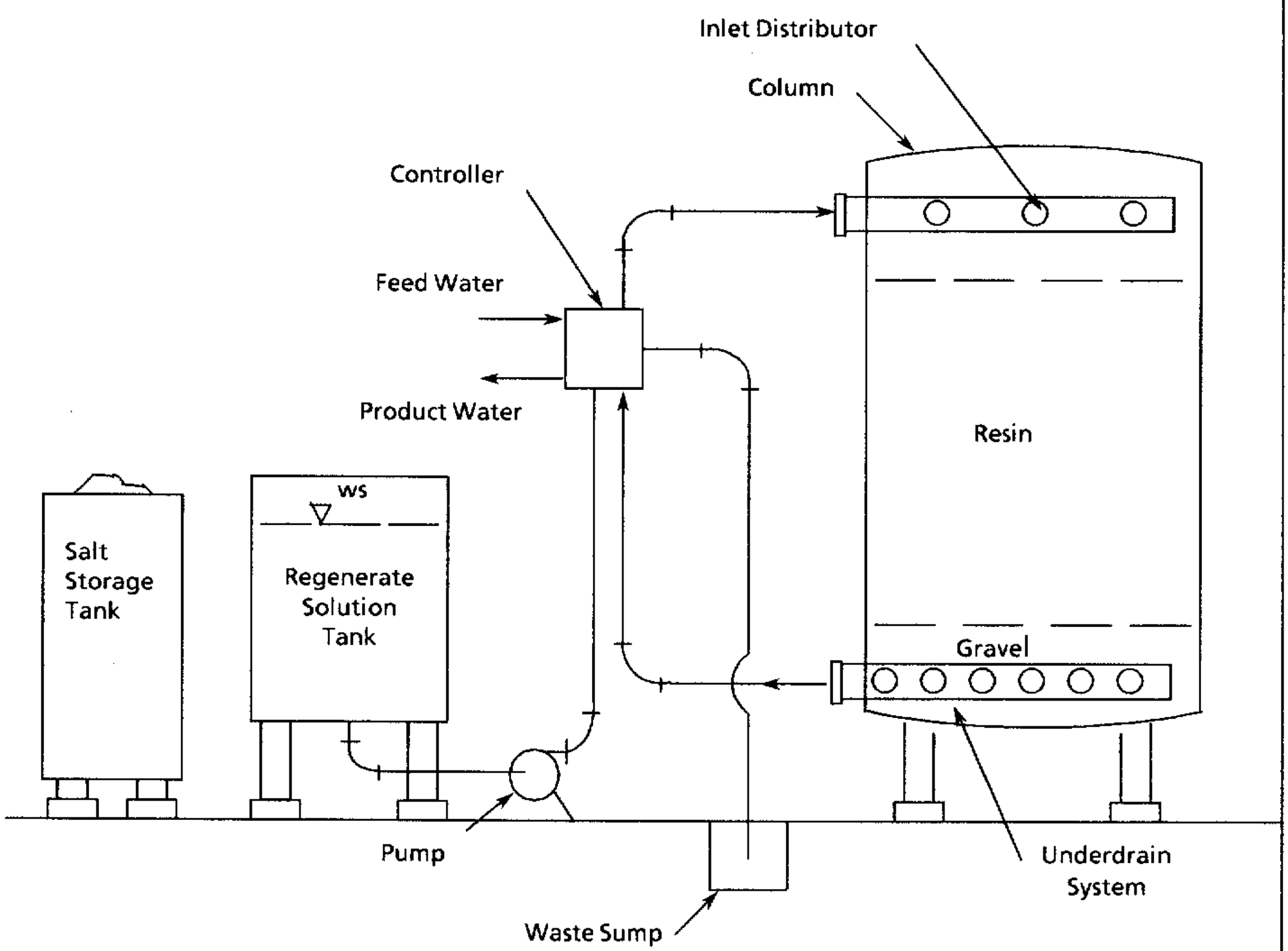


FIGURE 4. TYPICAL FIXED-BED COLUMN EQUIPMENT FOR SOFTENING, USING A SODIUM-CHARGED RESIN

When the feed passes through the condenser tubing, the energy of the condensing vapor preheats it. The process stages operate in series with decreasing pressure to increase the operating temperature range.

There are three major distillation processes now being used in the industry:

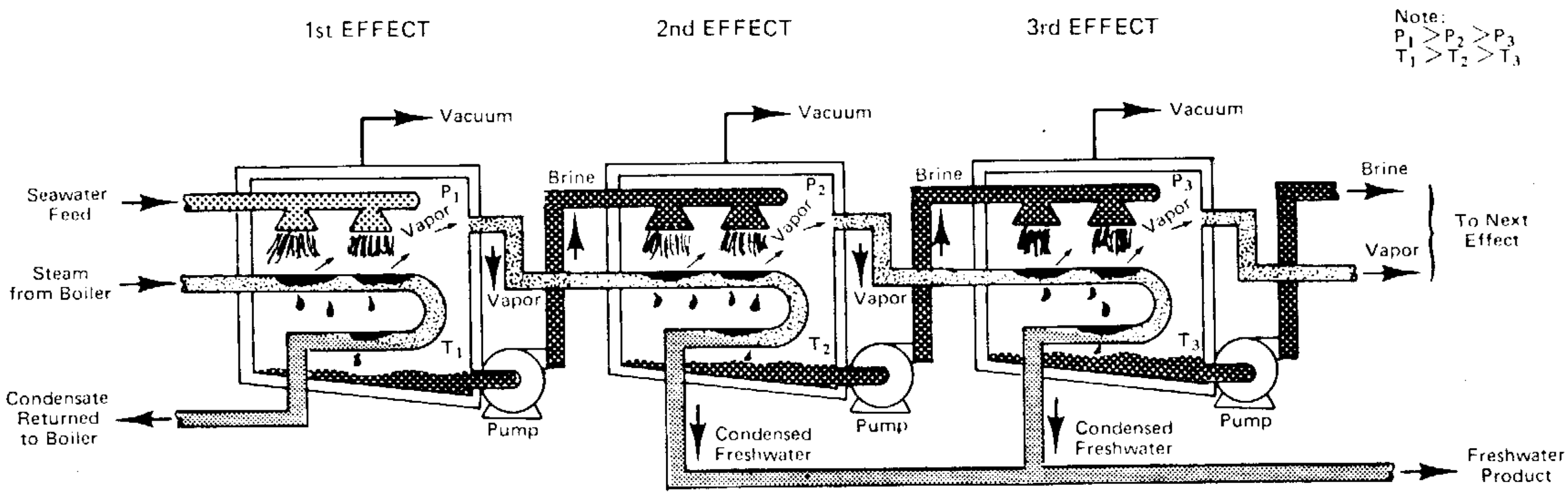
a) Multieffect Evaporation
b) Multistage Flash
c) Vapor Compression

Figures 5, 6 and 7 depict the distillation processes schematically. Most distillation processes use seawater for desalting. The U.S.A.I.D. Desalination manual by CH2MHill contains a detailed description of the distillation processes (2).

REVERSE OSMOSIS

Reverse Osmosis is a membrane separation process. In this process water from a pressurized saline solution separates from the solutes and flows through an appropriate membrane. Consider a membrane having a salt solution on one side and pure water on the other side. Any external pressure applied on the solution side will cause water to pass through the membrane to the dilute side.

This passing of the water from the solution side is dependent on the osmotic pressure of the solution. For example, sea water has an osmotic pressure of 29.6 atmospheres (435 psi) at 25 degrees centigrade. For practical purposes, one estimates the osmotic pressure



Notes:
1. This drawing is greatly simplified.
2. A final condenser such as shown on Figure 3-10 is necessary for operation.

FIGURE 5. CONCEPTUAL DIAGRAM OF A HORIZONTAL-TUBE MULTIPLE-EFFECT (HTME) DISTILLATION PLANT

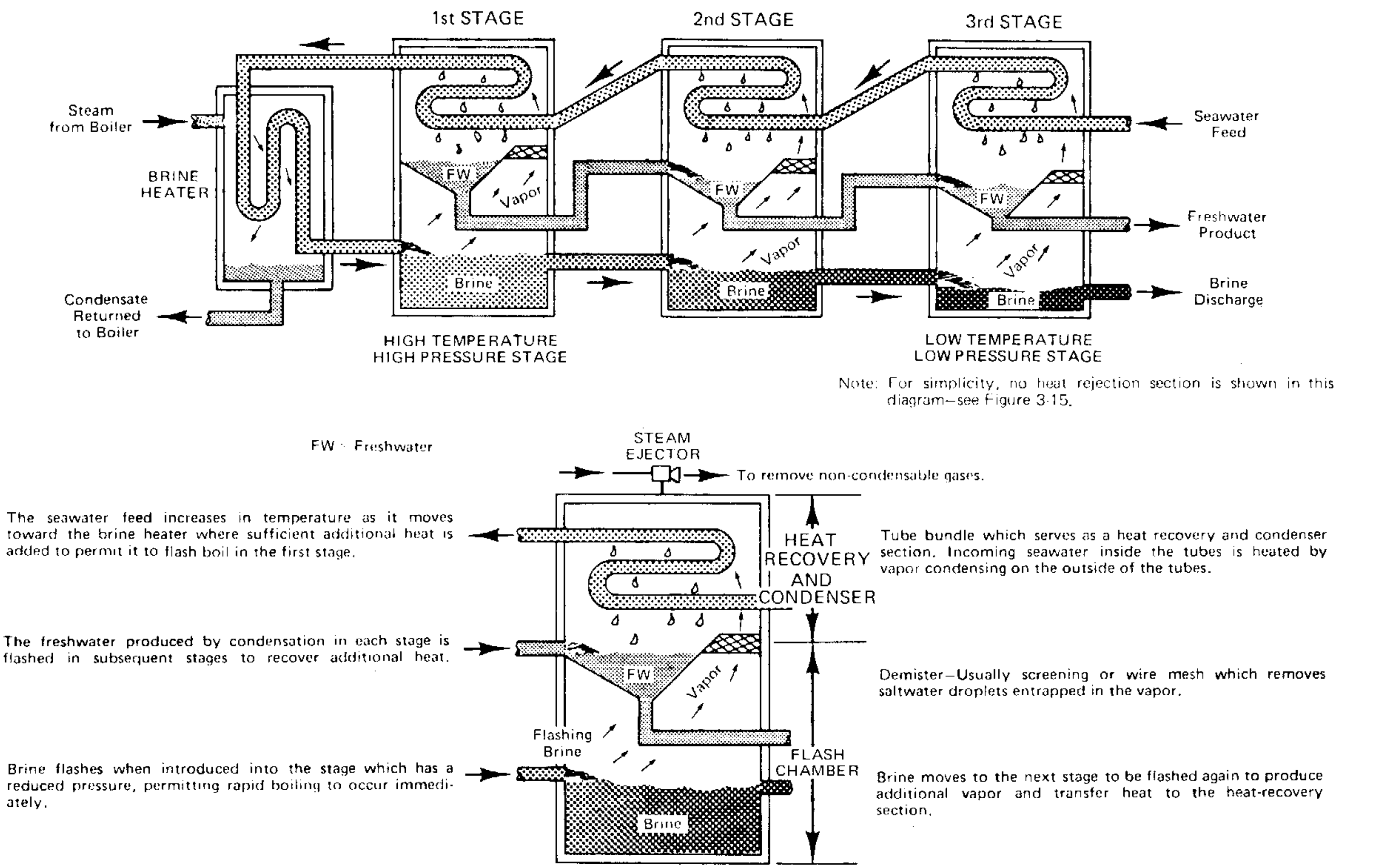


FIGURE 6. CONCEPTUAL DIAGRAM OF THE MULTISTAGE FLASH (MSF) PROCESS

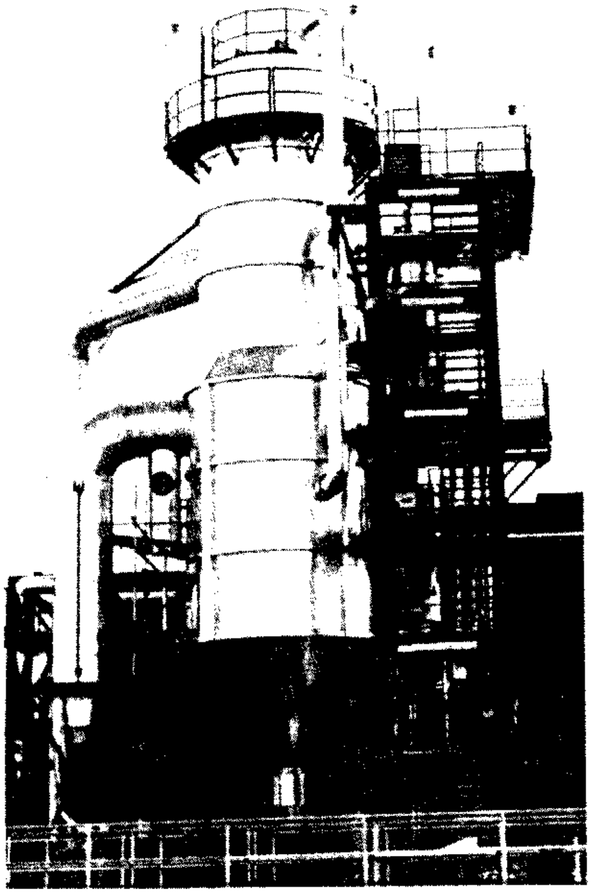


Photo Courtesy of RCC

A vertical-tube vapor compression unit to concentrate brine from a coal-fired generating station in southwestern USA. This unit processes about 0.225 mgd [852 m^3/d] of brine with a freshwater recovery of up to 98%.

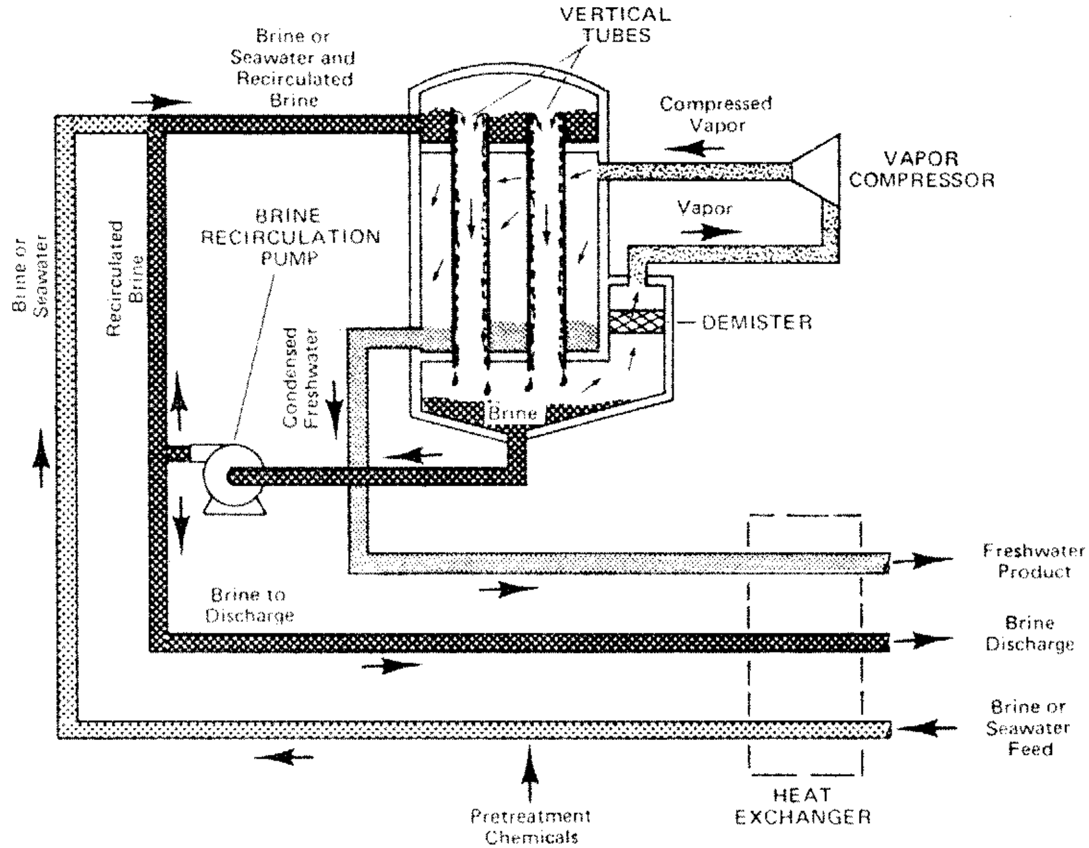


FIGURE 7. SIMPLIFIED FLOW DIAGRAM FOR A VERTICAL-TUBE VAPOR-COMPRESSION PROCESS

to be 1 psi per 100 mg/l of dissolved solids. Brackish water with 2000 mg/l sodium chloride will therefore have an osmotic pressure of approximately 20 psi.

Flow through the membrane occurs even with an applied pressure less than the osmotic pressure of the solution. For brackish water the pressure applied can be less than 20 psi. The RO process, however, needs considerably higher pressure than the osmotic pressure in the process. This higher pressure accomplishes the dual tasks of high flow and good salt rejection.

One of the greatest attractions of RO is that it more closely approaches the ideal minimum energy of separation for most applications. The actual energy required by an RO plant may be ten to twenty times the ideal minimum energy. This is one tenth as much as is required by some operating technologies, which indicates there is significant room for improvement before RO reaches its theoretical potential(8). (Figure 8).

The major energy use in the reverse osmosis process is in the pressurization of the feed water. For brackish water desalination, the operating pressure for the older membranes ranged from 300 to 400 psi. For sea water desalination it ranged from 800 to 1000 psi. The newer membranes require only half of the aforementioned cited pressure for brackish water conversion. This reduction of applied pressure from 400 psi to 250 psi has reduced power requirements by 3 KWH at 75 percent product recovery (12).

More seawater Reverse Osmosis plants are being installed in mid-eastern countries as they require less energy to operate. Additionally, seawater RO plants require less time to install than distillation plants.

Membranes available For Reverse Osmosis Desalination:

Introduction of RO as a process for desalting brackish water on a commercial basis started in 1965. At that time the only membrane available was cellulose acetate. In 1970 duPont introduced the polyamide membrane Permasep B9. By 1975, many manufacturers were supplying cellulose acetate membranes.

Additionally, two new membranes, Teijin's PBIL polynebzimidazolone membrane and UOP Fluid Systems' PA300/RC100 thin film composite membrane, were introduced. RO membranes for commercial use are usually in spiral wound or hollow fine fiber bundles. (Figures 9 through 12).

Spiral wound configurations use membranes in the form of sheets of film. Membrane material may be cellulosic acetate, triacetate, or a composite material. In the spiral wound design, the membrane seals in an envelope with a supporting grid on the inside. The membrane is about 4 microns thick.

The hollow fine fiber configurations use membranes in tubular form. Materials for the hollow fine fiber may be aromatic polyamide or a blend of cellulosic acetates. The membranes have an outside diameter of about 100 to 300 microns and an internal diameter of about half this. Normally, the fiber loops in a U-shape so that both ends embed in a single plastic tube sheet. Pressurized brackish or sea water enters into the vessel along the outside of the hollow fibers. The envelop wraps around a central collecting tube to ease placing it in a tubular pressure vessel. The hollow fine fiber design places many hair-like hollow fiber membranes in a pressure vessel.

Basically, a RO system consists of four major components. 1) pretreatment, 2) high pressure pump, 3) membrane assembly and, 4) post treatment for stabilization.

The process of RO desalting is as follows. First, the incoming water from wells receives treatment for scale control, pH adjustment, and the removal of suspended solids. This treated water then passes through the high pressure pumps to an appropriate pressure required by the membranes.The membranes housed in the membrane assembly stops the passage of salts and permits passage of almost salt free water. Feed water supplied to the membrane assembly produces fresh water and concentrated brine. The product water from the membrane assembly needs stabilization for pH adjustment and/or degasification before being transferred to the distribution line (Figure 13).

RO membranes are arranged in four basic configurations for design purposes. These are single, parallel, reject staging, and product staging.

The simplest configuration is single. Membrane assembly limits the quantity of water produced from this configuration. For brackish water RO, the single configuration yields anywhere from 45 to 55 percent product recovery. Parallel configuration increases water production, as there are two membranes producing water. Reject staging is used to increase water recovery from the system (Figure 14). Product staging uses two separate process trains run in series. Sea water desalination uses this configuration. In this staging, feedwater to the second stage

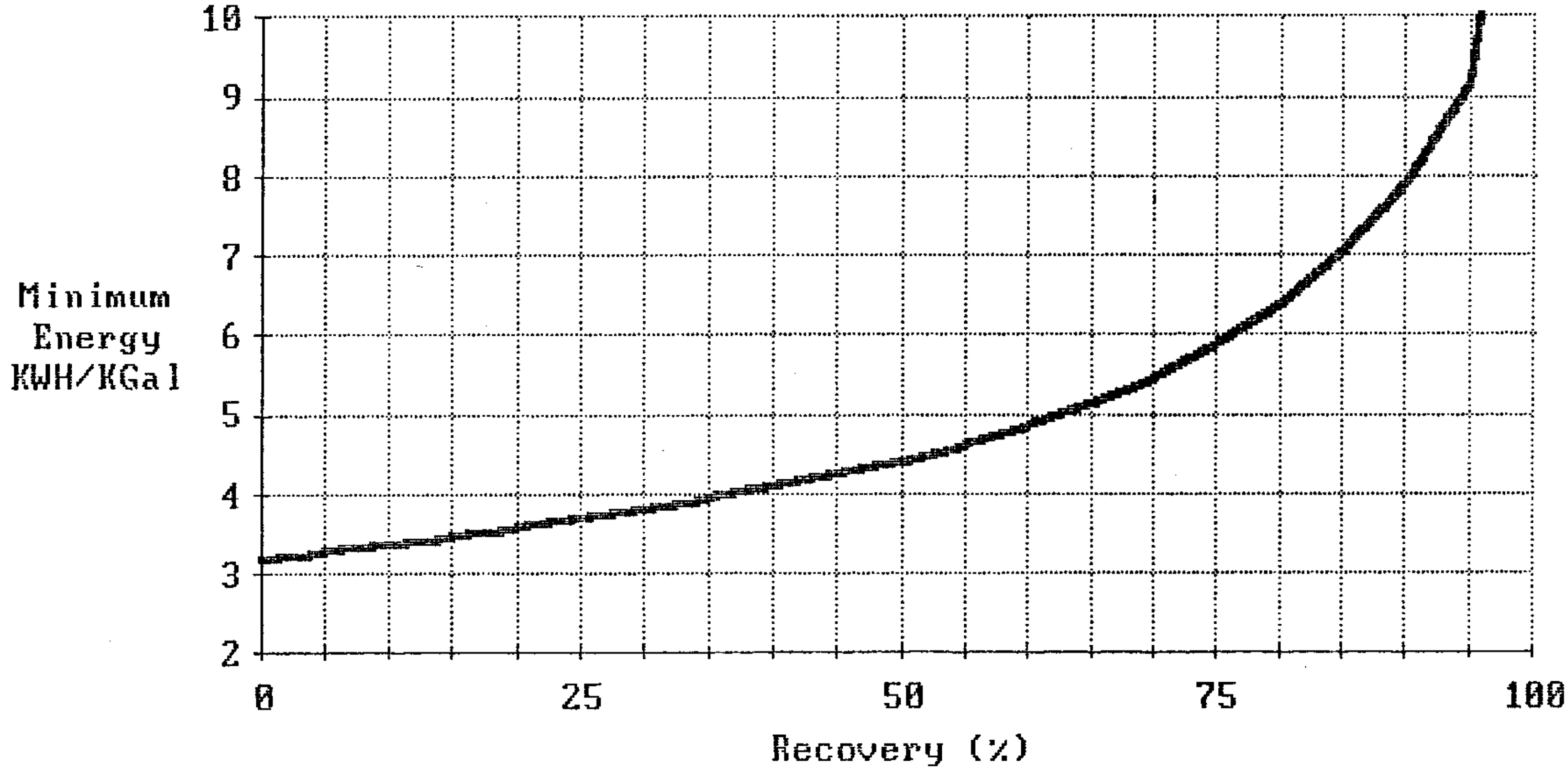
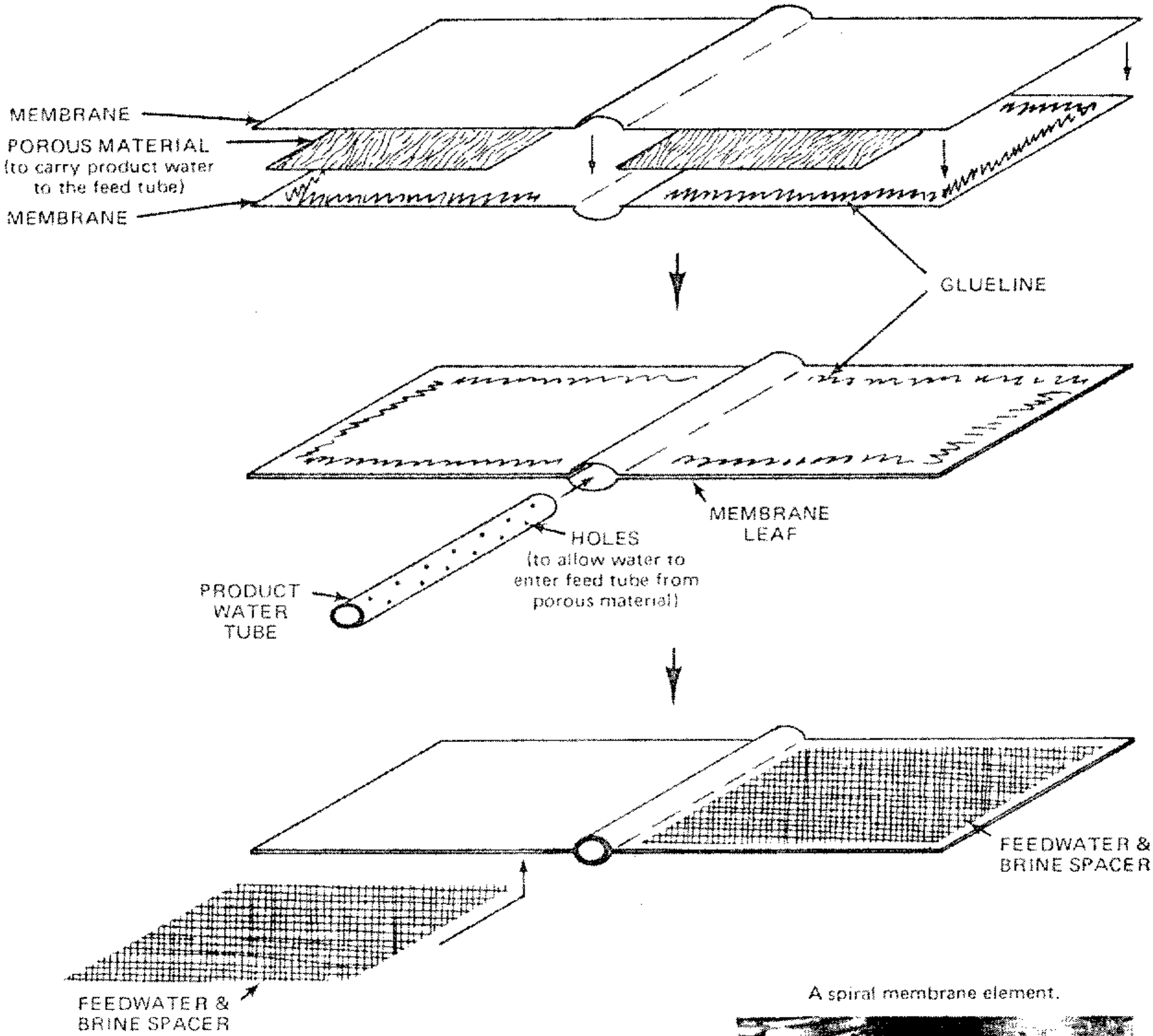
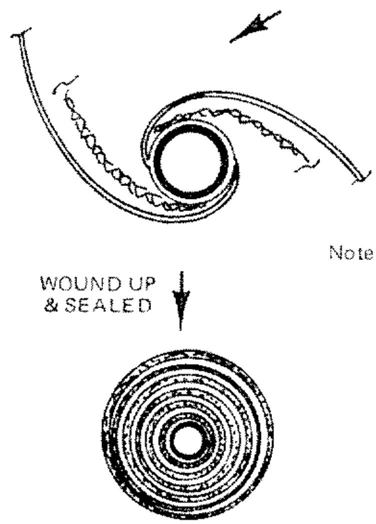


FIGURE 8. MINIMUM ENERGY OF SEPARATION VS RECOVERY RATIO (3.5% NaCl SOLUTION)





Note: This diagram shows the internals of a spiral membrane. This is not, however, the step-by-step method by which a factory manufactures membranes.

A spiral membrane element.

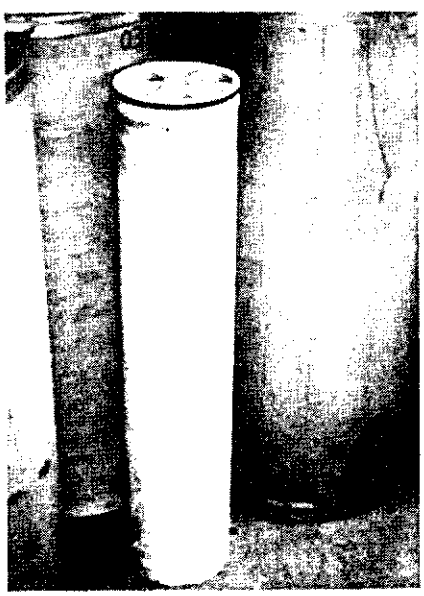
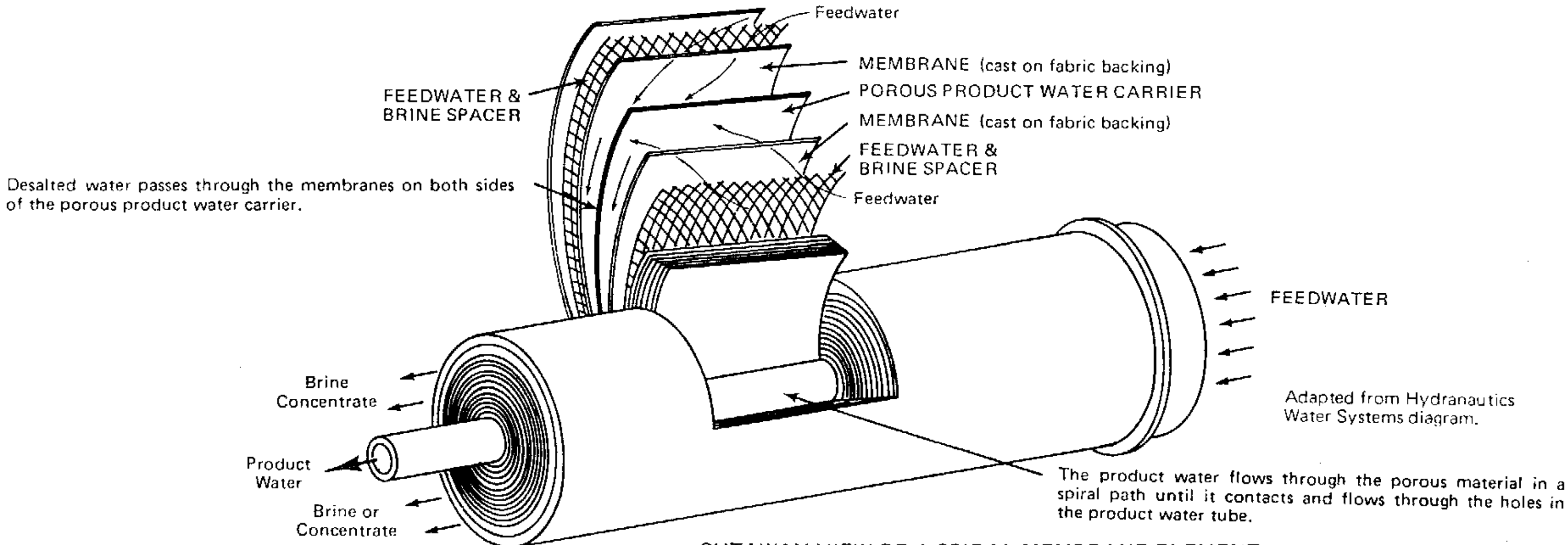
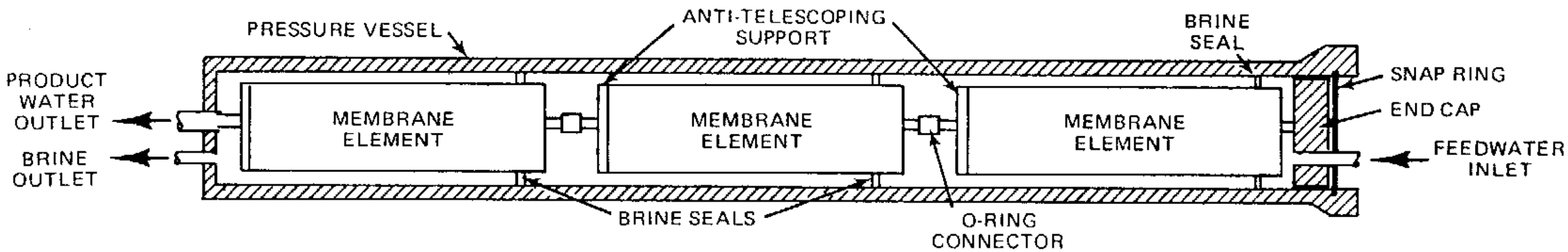


Photo Courtesy of O. K. Buros.

FIGURE 9. INTERNAL CONSTRUCTION OF A SPIRAL MEMBRANE



CUTAWAY VIEW OF A SPIRAL MEMBRANE ELEMENT



CROSS SECTION OF PRESSURE VESSEL WITH 3-MEMBRANE ELEMENT

FIGURE 10. SPIRAL MEMBRANE-CUT-AWAY VIEW WITH ELEMENTS IN A PRESSURE VESSEL

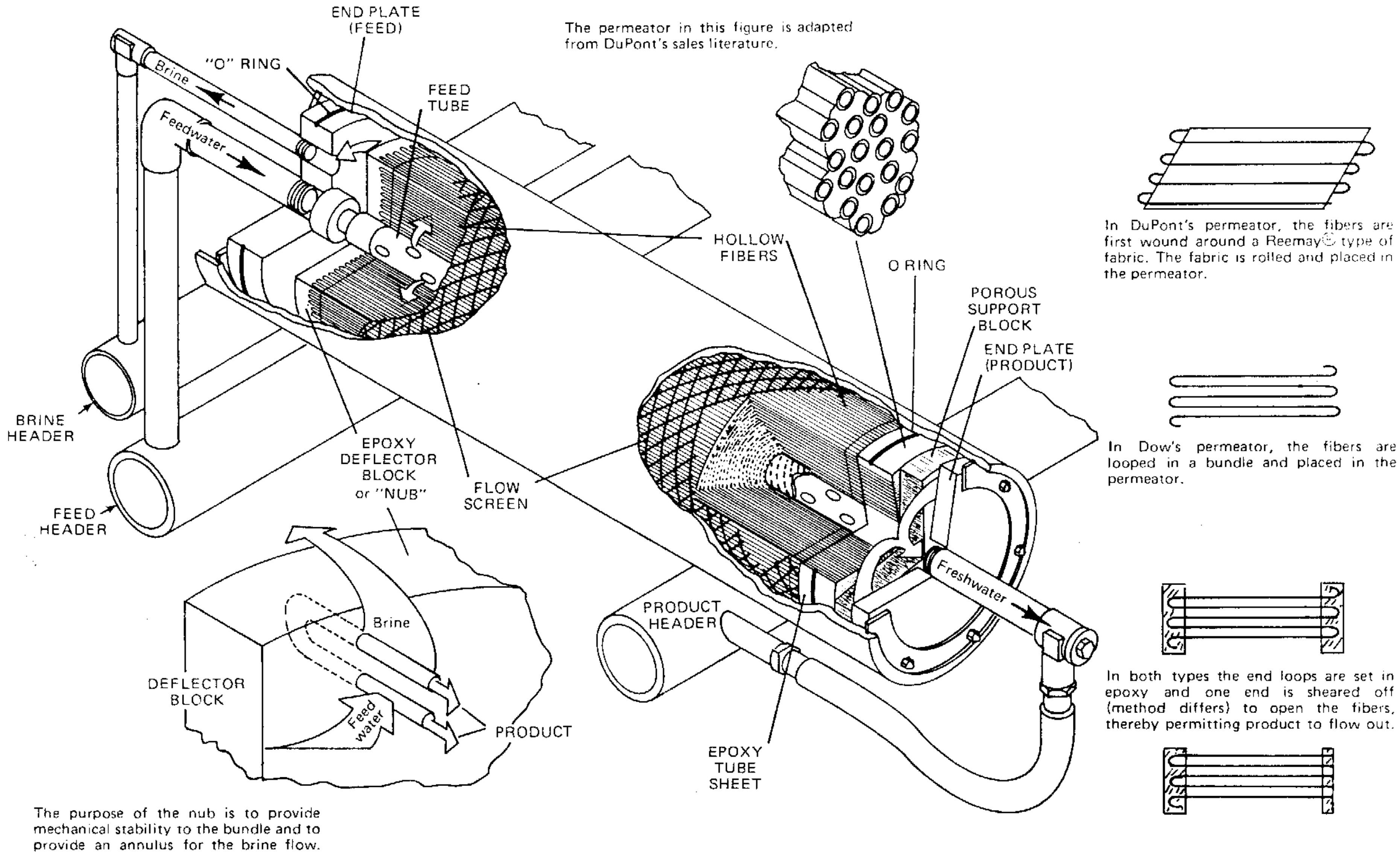


FIGURE 11. PERMEATOR ASSEMBLY FOR HOLLOW FINE FIBER MEMBRANES

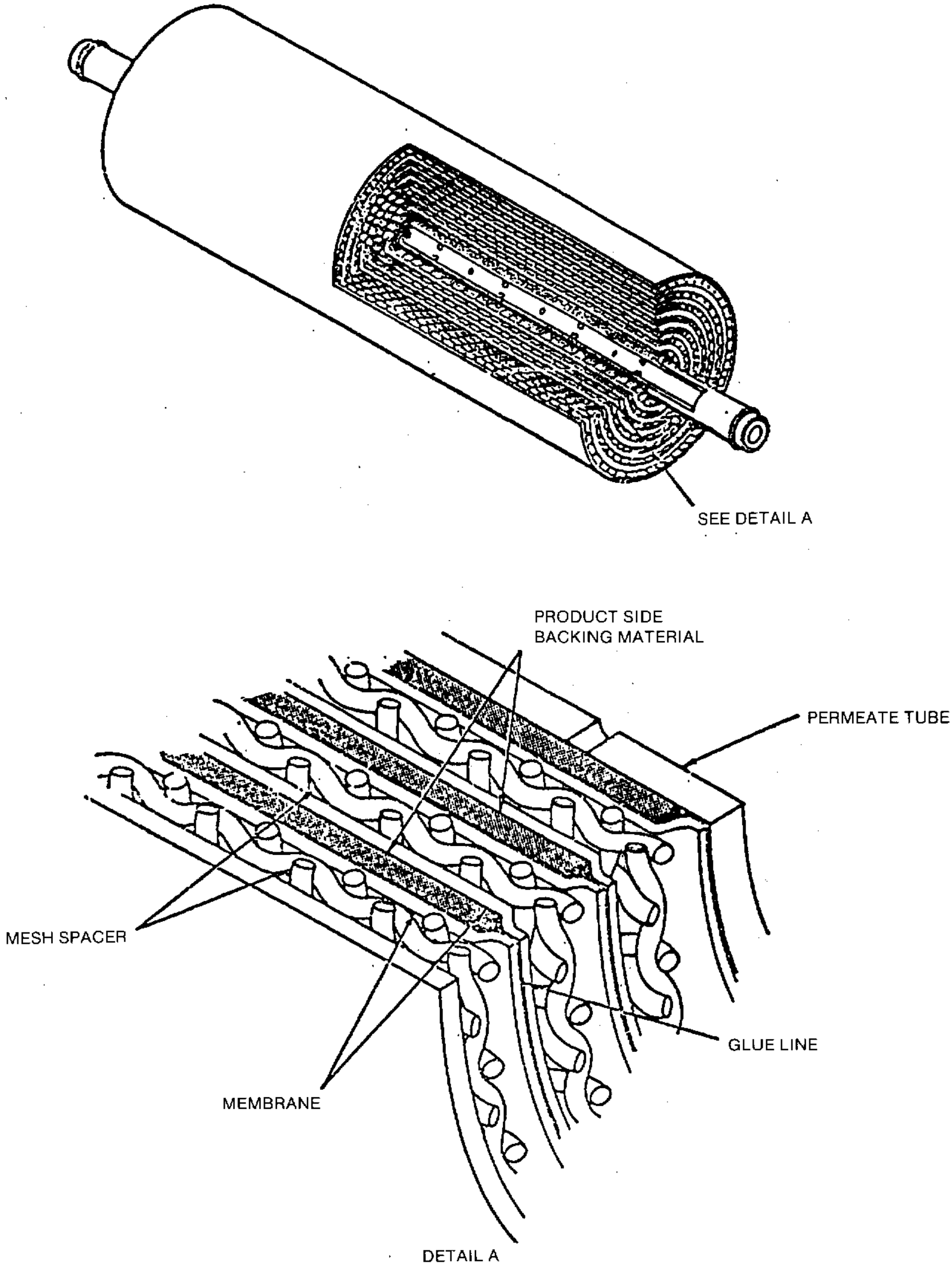
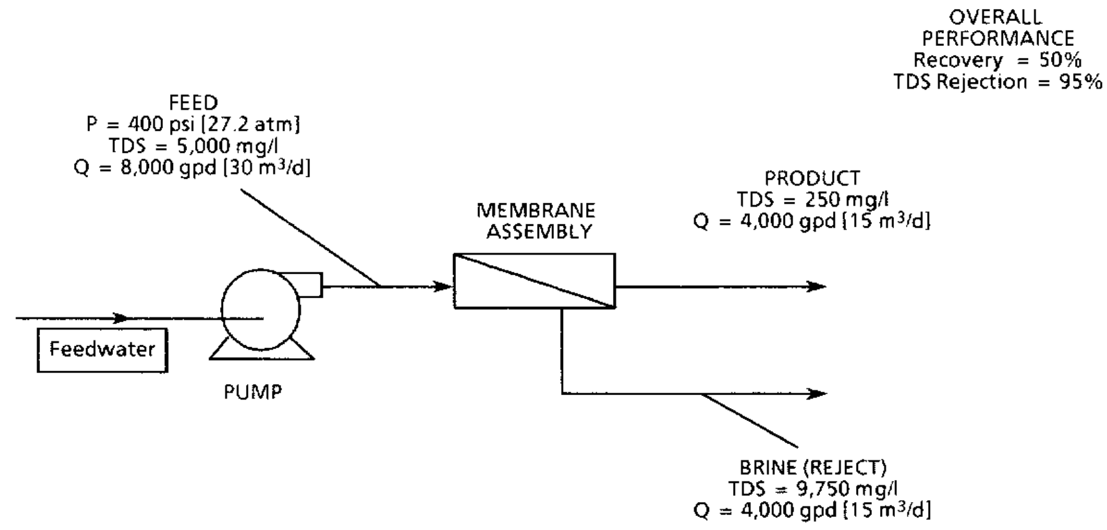
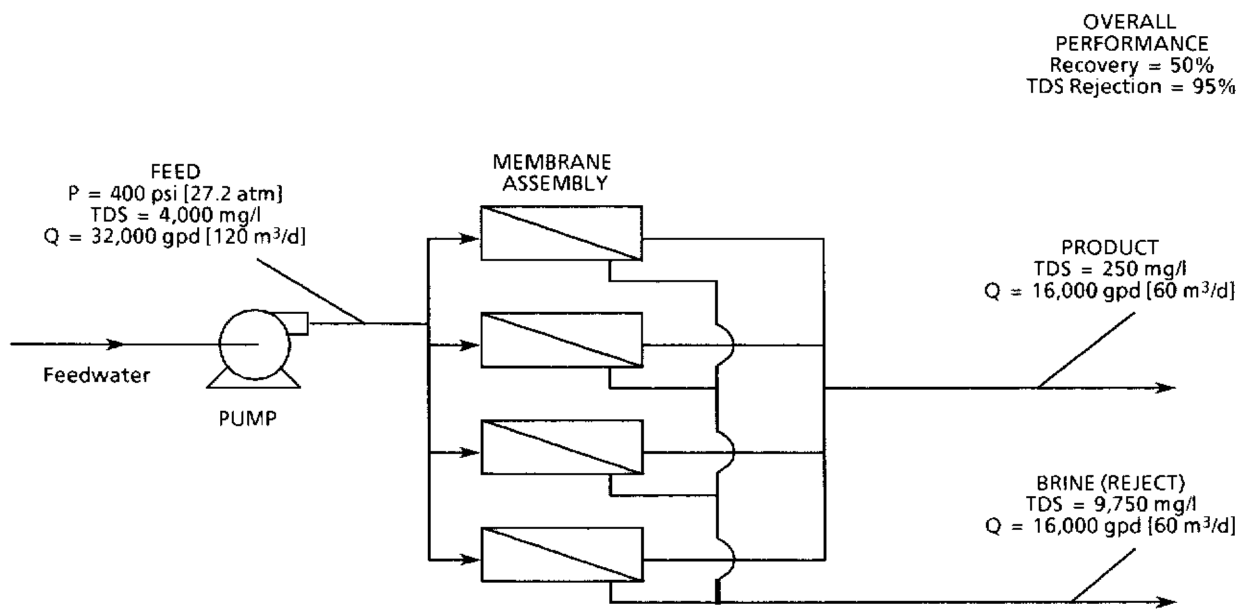


FIGURE 12. DETAILS OF SPIRAL WOUND MODULE CONSTRUCTION

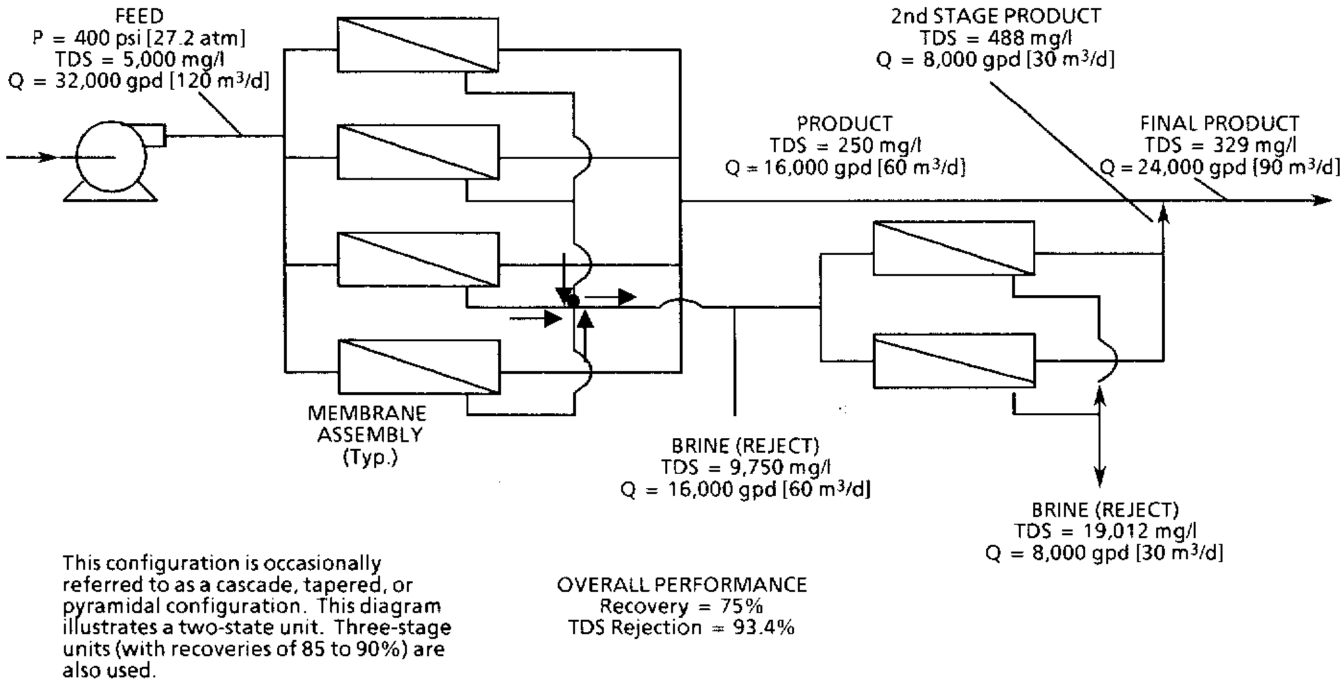


SINGLE STAGE WITH A SINGLE MEMBRANE ASSEMBLY

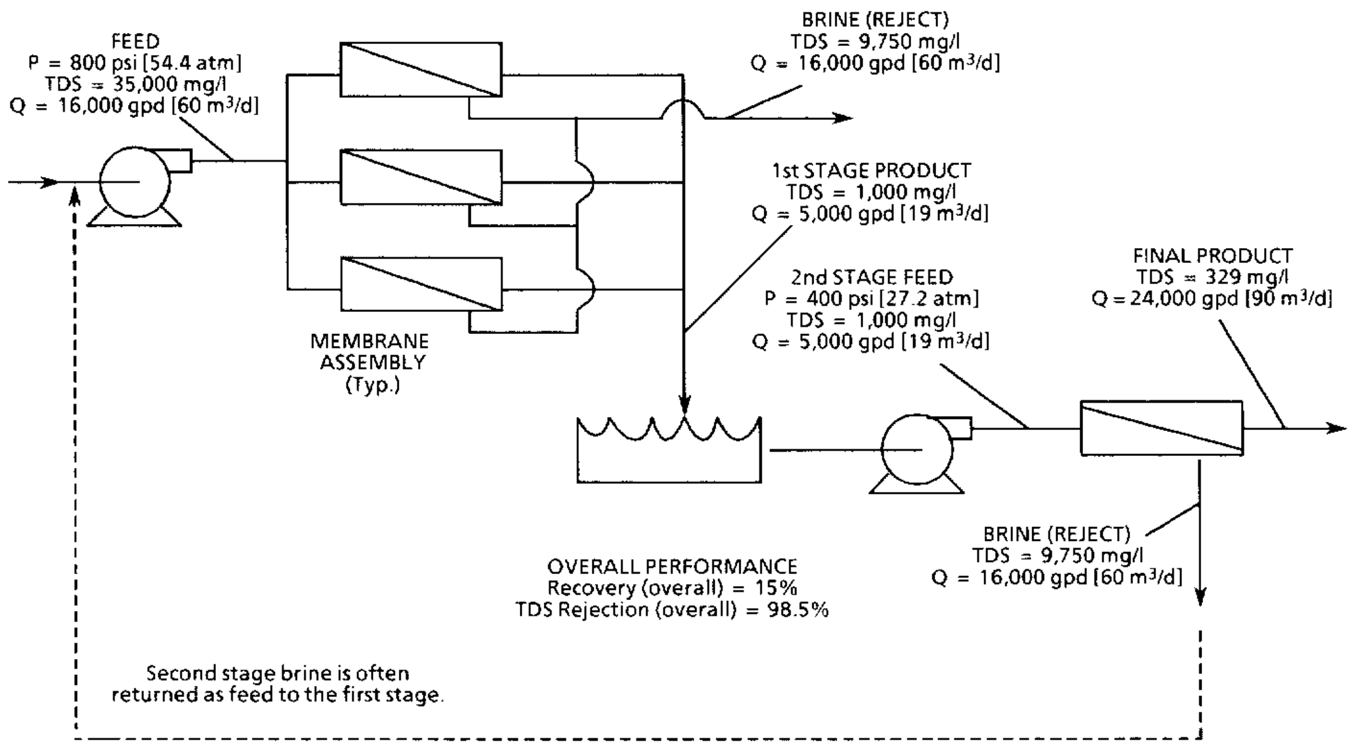


SINGLE STAGE WITH PARALLEL MEMBRANE ASSEMBLIES

FIGURE 13. SINGLE STAGE RO PLANT CONFIGURATIONS



MULTISTAGE WITH REJECT STAGING



MULTISTAGE WITH PRODUCT STAGING

FIGURE 14. MULTISTAGE PLANT CONFIGURATIONS

uses the product water from the first stage. Figure 15 depicts the process layout for the Florida Cape Coral plant which is an example of a two stage configuration.

Table 1 presents the list of commercial Reverse Osmosis Membranes (by general chemical type) now available in the market (15).

Performance Rankings Of Membranes For Brackish Water Desalting:

A variety of membranes for different uses are available in the market. One needs to evaluate the characteristics of each membrane, as well as the associated costs, before final selection. Membrane characteristics are flux and flux rejection. Flux is the rate of production per unit area of membrane.

A recent side-by-side testing of a variety of brackish water RO membranes took place at Englewood, Florida, during the period November 1984 through March 1985. This test included a CTA hollow fiber unit and two types of cellulose acetate spirals. In addition, three types of composite membrane spirals, and one type of asymetric polyamide spiral were also tested. Japanese composite membranes were not tested.

Table 2 summarizes the results ranking the membrances according to flux and flux rejection (15). and is evidence of the need to test the membrane in a pilot study before selection and installation. The table shows that FilmTec BW304040 had the highest flux rate as well as the lowest flux decline. From a membrane characteristics point of view, it was the best among the membranes tested at the above site. However, one needs to consider other factors, especially cost, before choosing a particular membrane for design.

New Chemicals For Pretreatment Of Feed Waters to RO Plants:

RO feed water must be disinfected to prevent slime formation and potential microbiological

TABLE 1. LIST OF COMMERCIALLY AVAILABLE REVERSE OSMOSIS MEMBRANES

•Fully Aromatic Polyamid:		
duPont	Permasep B9, B10	hollow fine fiber
duPont	Permasep B15	spiral(Low Pressure)
FilmTec	TW/Bw/SW/HR30	spiral
DDS	HR95, HR99	plate and frame
PCI	ZF99	tubular
Culligan	developmental product	spiral
•ArylAlkyl Polyamide/Polyurea:		
UOP	RC100 and PA300	spiral
Hydranautics	CPA	spiral
Toray	SU410	spiral
Nitto Denko	NTR7197	spiral
•Cellulose Acetate:	Numerous suppliers	all shapes
•Cellulose Triacetate:		
Toyobo	Hollowsep	hollow fiber
FilmTec (Dow)	Dowex LP,SP	hollow fiber
•Polyacrylonitrile:		
Sumitomo	Solrox	tubular, spiral
•Polybenzimidazalone:		
Teijin	PBIL	tubular, spiral
•Polyperazineamides:		
FilmTec	NF40, NF40HF	spiral
Nitto Denko	NTR7250	spiral
Toray	SU210	spiral
•Sulfonates Polyfuran:		
Toray	PEC1000	spiral
•Sulfonated Polysulfone:		
DSI	Desal Plus	spiral
Millipore	PSRO	spiral

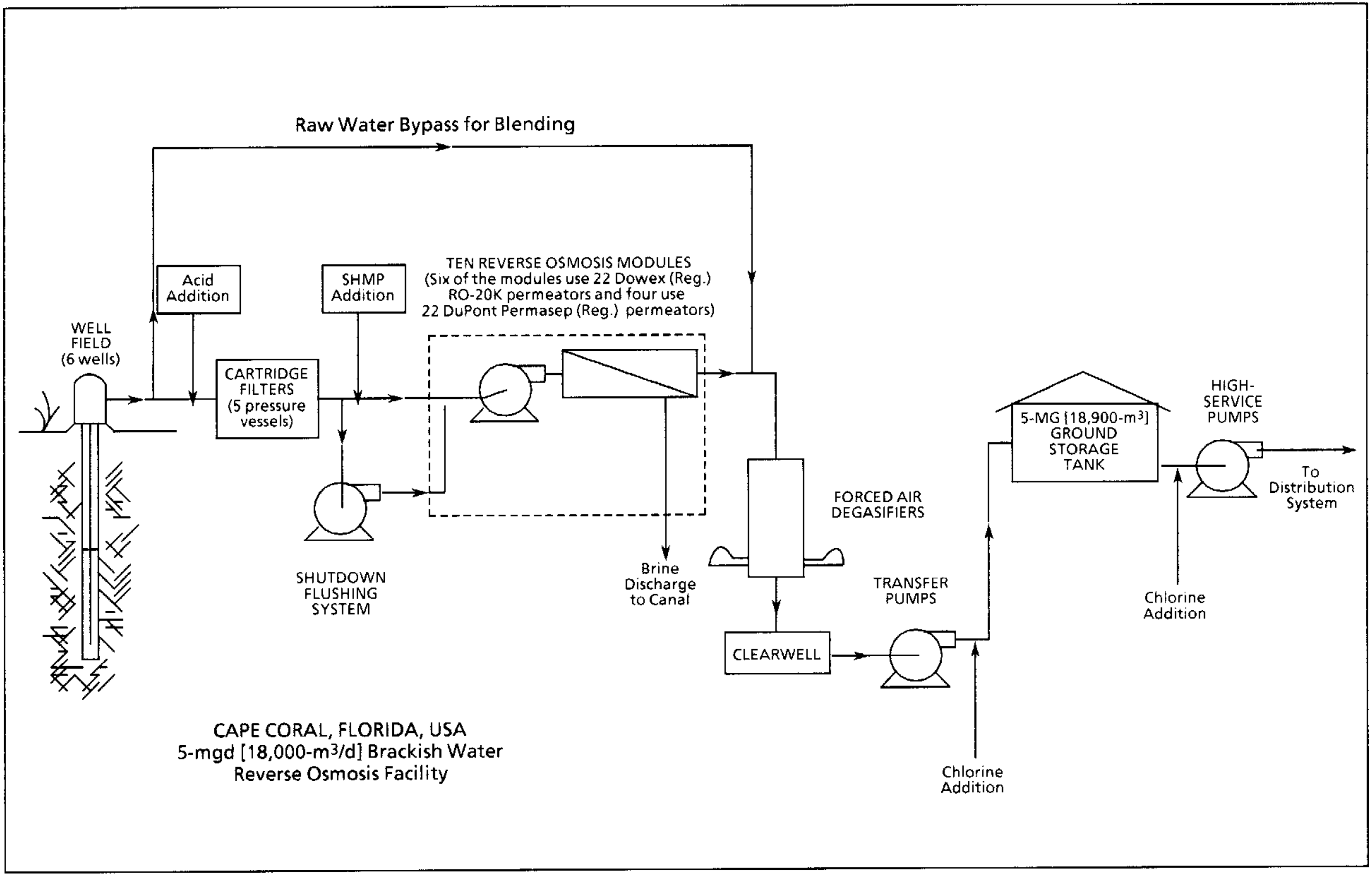


FIGURE 15. PROCESS FLOW DIAGRAM OF THE CAPE CORAL REVERSE OSMOSIS PLANT

TABLE 2. RANKING OF BRACKISH WATER MEMBRANES ACCORDING TO FLUX AND FLUX REJECTION

Membrane	Flux (gfd/250 psi)* 24 Hr.	2000 Hr.	Flux Decline Slope(m)
FilmTec BW304040	28.4	24.2	-0.075
UOP 4021 LP	23.0	19.9	-0.130
Hydranautics 430A1625 CPA	22.9-24.2	17.9-18.9	-0.13 to -0.14
DuPont(B15) Model 3441	17.5	13.1	-0.19
Toray Sc4100C	11.7	10.5	-0.06
Dow Dowex Ro LP9505	4.5**	3.8**	-0.055
UOP 4200 Hr Magnum	***	***	***

* Data normalized to 250 psi; actual test pressure varied for each membrane.
** Does not take into account membrane packing factor for hollow fiber versus spiral element design.
*** Dropped from comparison testing due to excessive feed pressure requirement.

degradation of membrane polymers. Chlorine was used for disinfection. However, chlorine came under attack during the seventies because of the appearance of trihalomethane (THM).

During this period, ozone, chlorine dioxide, and other halogen compounds were tested as substitutes for chlorine. Most of the RO membranes are sensitive to ozone and halogen compounds. The following conclusions were derived from the study conducted at the University of California (8):

1. Cellulose acetate membranes are resistant to halogens and halogen derivatives.
2. Polyamide type membranes are sensitive to chlorine and bromine, but show reasonable resistance with appropriate pH control.
3. Ozone damaged all membranes tested; however, cellulose acetate showed some resistance at low pH levels. This type of membrane may resist low concentrations in systems designed for ozone disinfections.
4. All membranes are resistant to iodine.
5. Polyamide type membranes are resistant to chlorine dioxide at near-neutral pH. This chemical clearly attacked membranes at high pH by oxidation.
6. DuPont B-9 membranes chemically combine with chlorine during exposure, which decreases the viscosity of polymer solutions in dimethyl sulfoxide.
7. Chlorine uptake data followed pseudo first order kinetic reaction.

The above results show that chlorine can still be used, with caution, as a disinfectant in RO plants. Sodium hexametaphosphate and acid are also added as part of the RO pretreatment process. This has been an almost universal practice.

Starting in 1983-84, several field trials were made using other additives. These additives were based on the polyacyrilics used for scale control in high temperature plants. Trials were made at installations at Cape Coral, Sarasota, and Venice.

The city of Cape Coral started using Pfizer Chemical Company's anti-scalent FLOCON 100. This chemical is a liquid polymer designed to inhibit mineral scale formation in RO systems.

Pfizer (7) reports that the chemical is effective against calcium carbonate, calcium sulfate, and strontium sulfate scale. The chemical, unlike sulfuric acid, is noncorrosive and safe. The plant superintendent for Cape Coral states that Flocon has lowered the anti-scalent feed from 5 mg/l to 3 mg/l. He also stated that Cape Coral plants still achieve full and effective anti-scalent protection. The city saved 15% on anti-scalent costs alone by reducing the dosage. The city is now producing high quality water for $.48/1000 gallons. This does not include capital recovery costs, however (7).

Recently, DuPont, Inc., has approved this new chemical for its membranes, and Water Factory has also switched to Flocon 100.

HISTORY OF DESALINATION GROWTH IN SOUTH FLORIDA

South Florida receives an average of 55-60 inches of rain per year which is seasonal in nature. Most of the rain falls during the months of March through October. During these months vast quantities of water are discharged to the ocean due to lack of storage space and flooding problems. Water is released from the storage areas to coastal canals during dry months to maintain optimal canal levels. Optimal canal levels prevent salt water from moving inland. These canal waters also recharge aquifers. In south Florida, a majority of utilities, agricultural, and industrial users withdraw water from these aquifers. Almost 90-95 percent of the water withdrawn for all these uses comes from shallow ground water.

During the rainy season, the aquifers from which the water is withdrawn gets recharged. However, water levels start to decline in early November due to heavy pumpage from utility companies, industries, and agricultural users. Sometimes, if the area does not get rain for an extended period of time, water levels become critical. The District then imposes water cutbacks to prevent salt water from migrating inland to the well fields.

The majority of south Florida's population clusters around the coastal areas. In the past, coastal well fields which received recharge from major canals were adequate to meet demands during dry months. However, with the tremendous influx of population, the coastal utility companies are finding it hard to meet water demands during the dry months. Even during normal dry months, users face the possibility of water cutbacks due to salt water intrusion, etc., which is due to increased pumpage from these coastal well fields. More and more utility companies are now moving inland to develop well fields and they will transport water to the coastal areas. This alternative is costly and is not attractive politically.

For example, the city of Key West transported water from the Navy Well Field in Florida City. The conveyance distance is almost 120 miles. As the population of the Keys started to grow, Key West needed more water than the pipeline could convey. Therefore, Key West installed a 2.6 MGD distillation plant in 1967 to augment its potable water needs. This was the start of desalination activities in the state of Florida.

Sea water was the source of feed supply for this distillation plant. Key West had to desalt sea water as there are no brackish water formations in the Keys. This is not the case with other cities, and many other cities are using brackish water sources as feed water for their RO plants.

Commercial desalination of brackish water started in 1969 with the installation of a 2.0 MGD plant at Siesta Key. Sanibel Island was the second city to install a desalination plant which was an ED plant with a 1.2 MGD capacity. Later on, as the potable demand grew, Sanibel expanded the capacity of this plant to 2.1 MGD. Sanibel now has the capacity to desalt up to 4.5 MGD.

Rotunda West was the first city to install a large Reverse Osmosis plant in 1972. The city of Cape Coral installed a 3 MGD plant in 1977. Before installation however, several water supply alternatives were evaluated by the city. Reverse Osmosis ranked first in the selection process in terms of economics. Cape Coral now has desalt plants capable of producing approximately 14 million gallons of potable water a day.

Beginning in 1967, when Key West installed the first sea water plant, desalt plant installation in Florida has grown. In 1979-80 Key West suffered a severe water shortage during the winter months. To alleviate this problem, the city entered into a contract to lease a 3 MGD sea water RO plant for a period of 2-3 years. By 1984 Florida had desalt plant capacity in excess of 40 MGD. Florida was then one of the largest desalt water users in the nation.

Figure 16 depicts desalt plants location in Florida. The map shows most of the plants located along coastal areas. There are various short term projections for further expansion of desalination in Florida (5).

Presented in Table 3 are the various desalination plants, their capacity and usage, etc., in south Florida as of 1984.

Table 3 clearly depicts that southwest Florida has been the largest desalt water user in the past. Most of the desalt plants are Reverse Osmosis plants. These plants use the upper Floridan aquifer water as

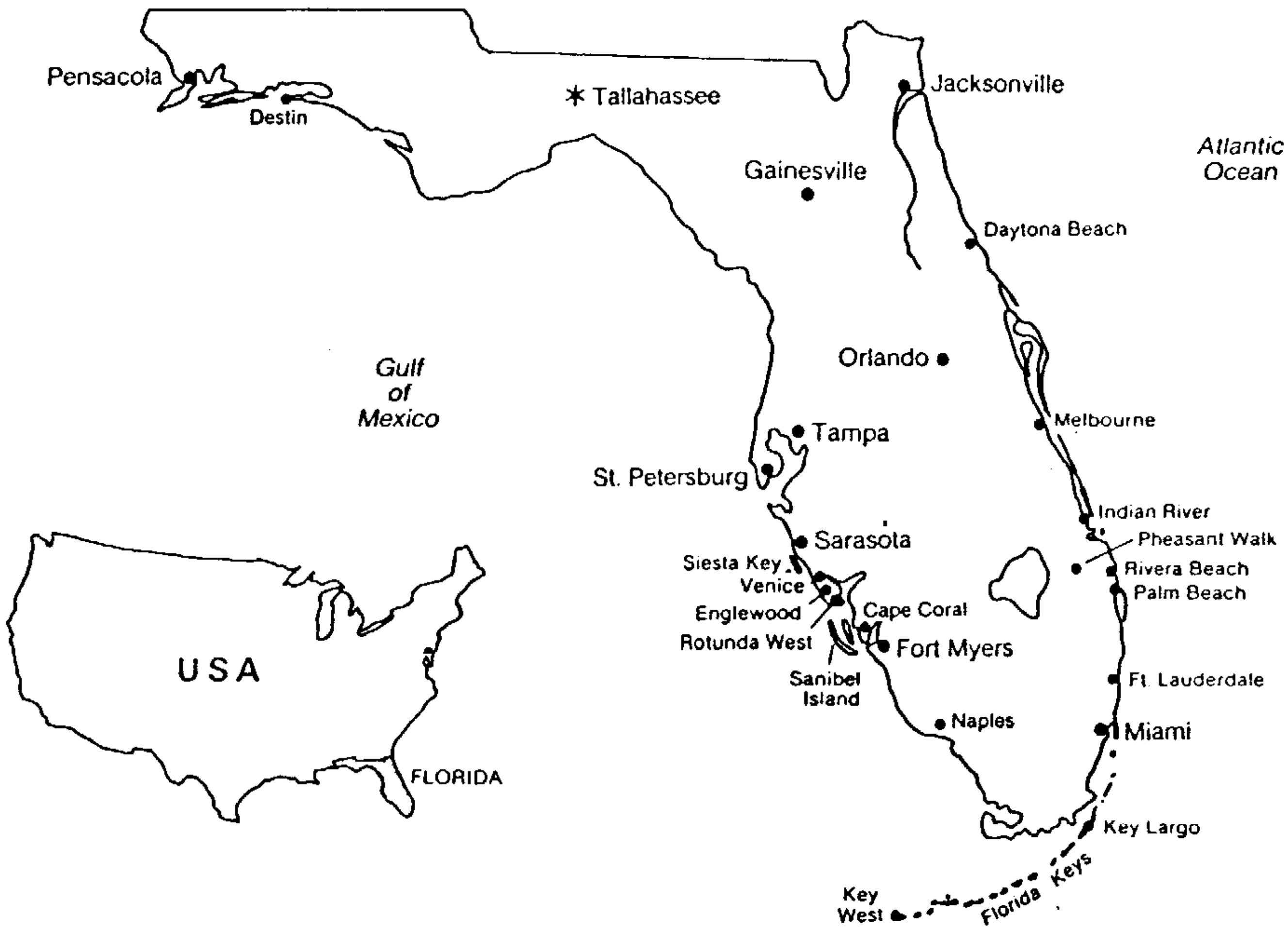


FIGURE 16. MAP OF FLORIDA

TABLE 3. DESALINATION PLANTS IN SOUTH FLORIDA

COUNTY	OPERATOR	CAPACITY (KPGD)	TYPE	USE
COLLIER	Pelican Bay District	500	RO	Municipal
DADE	Beverage Canners	100	RO	Industrial
LEE	Bonita Springs	48	RO	Municipal
LEE	Cape Coral	5000*	RO	Municipal
LEE	Cape Coral	9000*	RO	Municipal
LEE	Captiva Island	35	RO	Municipal
LEE	FPL	38	RO	Power
LEE	Pine Island	825	RO	Municipal
LEE	Sanibel Island	2200	ED	Municipal
LEE	Sanibel Island	1800	RO	Municipal
LEE	Sanibel Island	500*	RO	Municipal
LEE	Iona Trailer Park	20	RO	Municipal
LEE	Sunset Captiva	17	RO	Municipal
LEE	Gulf Coast Resort	28	RO	Public
LEE	Useppa Island	27	RO	Public
LEE	Pines of Punta Gorda	30	RO	Public
LEE	Yoder Brothers	56	RO	Public
MARTIN	River Club Condominium	57	RO	Municipal
MARTIN	Indian River Plantation	50	RO	Public
MARTIN	Joe's Point	120	RO	Public
MARTIN	Sailfish Point	150	RO	Public
MONROE	Key Largo	300	RO	Tourist
MONROE	Rock Harbor	1000	RO	Municipal
MONROE	Key Largo	630	RO	Municpal
MONROE	Key Largo	300	RO	Municipal
MONROE	Key West	2620	MSF	Municipal
PALM BEACH	Pheasant Walk	1080	RO	Municipal
PALM BEACH	PBC Utility	500	RO	Municipal
PALM BEACH	PBC Utility	250	RO	Municipal
PALM BEACH	Lake Park	25	RO	Industrial
PALM BEACH	Mangonia Park	30	RO	Municipal
PALM BEACH	PB Gardens	100	RO	Industrial
PALM BEACH	PB Gardens	108	Ro	Industrial
PALM BEACH	South Bay	33	RO	Municipal
PALM BEACH	WPB	27	RO	Municipal
PALM BEACH	WPB	260	RO	Municipal
PALM BEACH	Shelton Land & Cattle	14	RO	Municipal
PALM BEACH	Okeelanta Sugar	42	RO	Public
SAINT LUCIE	Hutchinson Island	40	RO	Municipal
SAINT LUCIE	Hutchinson Island	120	RO	Municipal
SAINT LUCIE	Hutchinson Island	150	RO	Municipal
SAINT LUCIE	Fort Pierce	30	RO	Municipal
SAINT LUCIE	Fort Pierce	30	RO	Municipal
SAINT LUCIE	Fort Pierce	32	RO	Municipal
SAINT LUCIE	Fort Pierce	75	RO	Tourist
SAINT LUCIE	Fort Pierce Utility	60	RO	Public
SAINT LUCIE	Harbor Fountain	19	RO	Public
SAINT LUCIE	Queen's Cove	10	RO	Public

* Low Pressure RO

feed water. The west coast of Florida has limited fresh water availability, and desalination is likely to increase. With the influx of population and excessive pumpage, even the brackish water from the upper Floridan zones are showing signs of stress. Cape Coral now withdraws a portion of its feed water from the lower Floridan aquifer zone.

Fresh water availability has not been a problem in the lower east coast until recently. However, demand is exceeding supply in various locations. The District's Water Supply and Development Plan, published in 1978, clearly demonstrates demand exceeding supply by 1990. By 1995, the plan shows a requirement of 80 MGD. Concerning the supply side, the plan shows limited capability of the existing supplies. A constant supply of 866 MGD was estimated to be available during dry months. The plan also stated that new regional scale systems (e.g., conservation areas, reservoirs, etc.) would be prohibitive from both cost and environmental points of view. This in turn, means that future water supplies may have to be provided by a combination of conventional and non-conventional sources on a local basis. Most of the major utility companies have already started evaluating different options of water supply, including desalination.

The Executive Summary for the Upper East Coast Planning area (SFWMD Water Supply & Development Plan, 1978) shows a yearly additional water requirement in excess of 2.2 MGD. The total demand however, including agricultural demands in St. Lucie and Martin Counties, was estimated to increase from 161 MGD in 1980 to 192 MGD by the year 2000. A recent study entitled: "Martin County Water Resource Assessment" pinpoints the limitation of surface water for potable uses from C-44 during dry months. The report states that additional withdrawal from C-44 will impose greater stress on Lake Okeechobee. Further, the report states that surficial aquifers in some localized areas in the study area will not be able to meet buildout demands. In such areas, the Floridan aquifer is a potential source of water when treated with desalination systems.

There are already 11 small scale desalt plants in the UEC. These plants were producing in excess of 200,000 gallons/day of potable water in 1979.

DSS engineers report to the U.S. Army Corps of Engineers divides the South Florida Water Management District area into three basins. They are Lake Okeechobee (Area 1), Lower East Coast (Area 2), and the Lower West Coast (Area 3) basins. In the Districts's terminology, the Upper East Coast area is the Okeechobee area.

DSS engineers report the following surpluses and shortages of water in each of the above areas (Table 4).

The surpluses and deficits shown in Table 4 apply to a typical average year condition. To meet these deficits, the report explores the application of desalination district-wide (5).

The report also indicates that reverse osmosis plants up to 6 MGD capacity can be less expensive than conventional water plants. RO is closely competitive up to a plant size of 10 MGD. For larger plants, the report states that conventional water treatment plants are more economical. It is important to note that conventional costs included the treatment of water for the high amount of Trihalomethane (THM) precursors. Free chlorine treated surface and ground waters of south Florida generate THM precursors.

The report concludes that desalination is a viable alternative for south Florida's water supply. The desalt alternative will achieve its goal of providing adequate supplies of agricultural, municipal, and industrial water. Additionally, the report also states that this option will improve the environment of the Everglades National Park.

The report provides a comparative unit treatment cost for RO and Conventional plants, (Table 5). Table 5 shows that the present cost of producing 1000 gallons of water from a conventional treatment plant is $3.90. However, a RO plant can produce the same quantity at a cost of only $1.40. RO can also use

TABLE 4. SURPLUSES AND SHORTAGES IN MGD

	Lake Okeechobee Area 1		Lower East Coast Area 2		Lower West Coast Area 3	
Year	Supply	Shortage	Supply	Shortage	Supply	Shortage
1980	804	-36	1342	+ 302	120	-10
1990	857	-125	1584	+ 374	135	-25
2000	893	-188	1637	+ 213	200	-40
2010	929	-232	1682	+ 62	240	-60
2020	947	-267	1718	-81	280	-80

TABLE 5. COMPARISON OF CONVENTIONAL VS. RO COSTS TO PRODUCE 1000 GALLONS OF PRODUCT WATER

PLANT CAPACITY (MGD)	RO COST (TDS UP TO 5000 MG/L) $/KGAL	CONVENTIONAL COST GROUND WATER $/KGAL
1.0	1.40	3.90
2.5	1.20	1.70
5.0	1.10	1.40
10.0	.98	1.00

economy of scale, the production cost decreases as the plant size gets larger.

SOURCE OF FEED WATER FOR RO PLANTS

Any source of water - surface water, reclaimed wastewater, brackish, or seawater can be feed water for Reverse Osmosis plants. In this report water is divided into four classes: 1) fresh, 2) brackish, 3) seawater, and 4) brine. Fresh water generally covers a TDS of up to 1000 mg/l, brackish water from 1,000 to 35,000, and seawater above 35,000. Brine is the reject water from desalination plants after pure water is removed. In south Florida, brackish water has been the sole source for reverse osmosis plants. Floridan aquifer water requires minimum treatment. Most of the Florida RO plants require only micron filtration, in addition to acid and sequestering agent addition. The exception has been the Keys seawater RO plant. Seawater from wells also requires minimum treatment. Surface water, in general, requires extensive treatment before the water can be passed through the membranes.

In the District area, brackish water is available for withdrawal from the Floridan aquifer. This aquifer lies below the Surficial aquifer. The elevation of the top of this aquifer varies from 100 feet to 1100 feet. Not all the Floridan aquifer is salty, however. In the northern part of the District where recharge occurs, Floridan aquifer water is fresh. The top of the aquifer in this area is only 100 to 400 feet below the ground (Figure 17). Public water supply in these northern areas use the Floridan aquifer.

In the lower east coast area, the Floridan aquifer has two distinct zones. The upper zone ranges in depth from 800 to 1150 feet (Figure 18). Wells drilled in this formation can yield approximately 2000-5000 gallons per minute. The upper zone yields water with total dissolved solids of 2000-3500 mg/l. As one moves south the total dissolved solid increases and surpasses the drinking water standards (Figure 19).

The lower zone extends to a depth of 1600 feet. The total dissolved solids of the lower zone (1400 to 1600 feet) is saltier. Total dissolved solids in this zone vary from 5,000 to 8,000 mg/l (3). Use of Floridan water has been minimal in the lower east coast. Monroe County uses a small quantity for RO desalination.

In the upper east coast, the depth of the Floridan aquifer generally ranges from 400 to 900 feet. The aquifer extends to a depth of 1500 feet. In this area well yield is dependent to a large extent on depth of penetration. Two distinct Floridan aquifer zones are present in this area; the first zone is 400-600 feet deep and the second zone is 900 to 1200 feet deep. Typical wells in the upper zone yield 300 to 500 gallons per minute (3). The lower zone can yield as much as 1000 to 2000 gallons per minute. These provide only the general figures on well yields. Rigorous testing of the aquifer at a particular site is necessary to predict the well yield accurately.

The total dissolved solids of the Floridan aquifer in this area range from 700 to 1000 mg/liter. TDS are variable with depth.

Floridan aquifer water blended with surface and surficial aquifer water generates a large volume for citrus irrigation. There are also small RO plants in the area which use this water as their feed water. Overall aquifer stress in the upper east coast is low. However, during periods of large withdrawal, the aquifer becomes over stressed, creating large drawdowns.

The Martin County Water Resource Assessment, prepared by the District, indicates as much as 113 MGD can be withdrawn from this source (19). A report on Floridan aquifer resource assessment for the

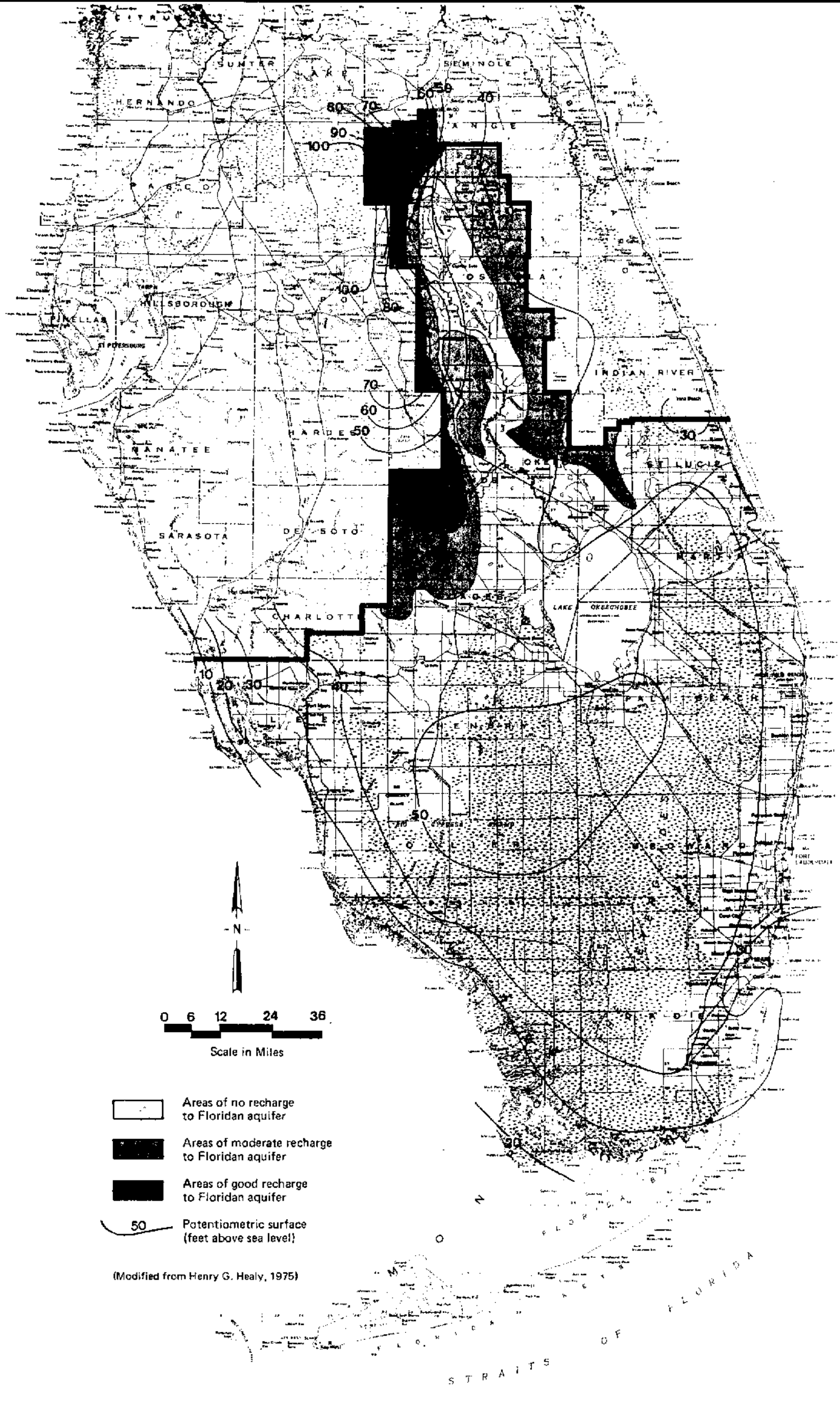


FIGURE 17. POTENTIOMETRIC SURFACE IN THE UPPER PART OF FLORIDAN AQUIFER, SFWMD

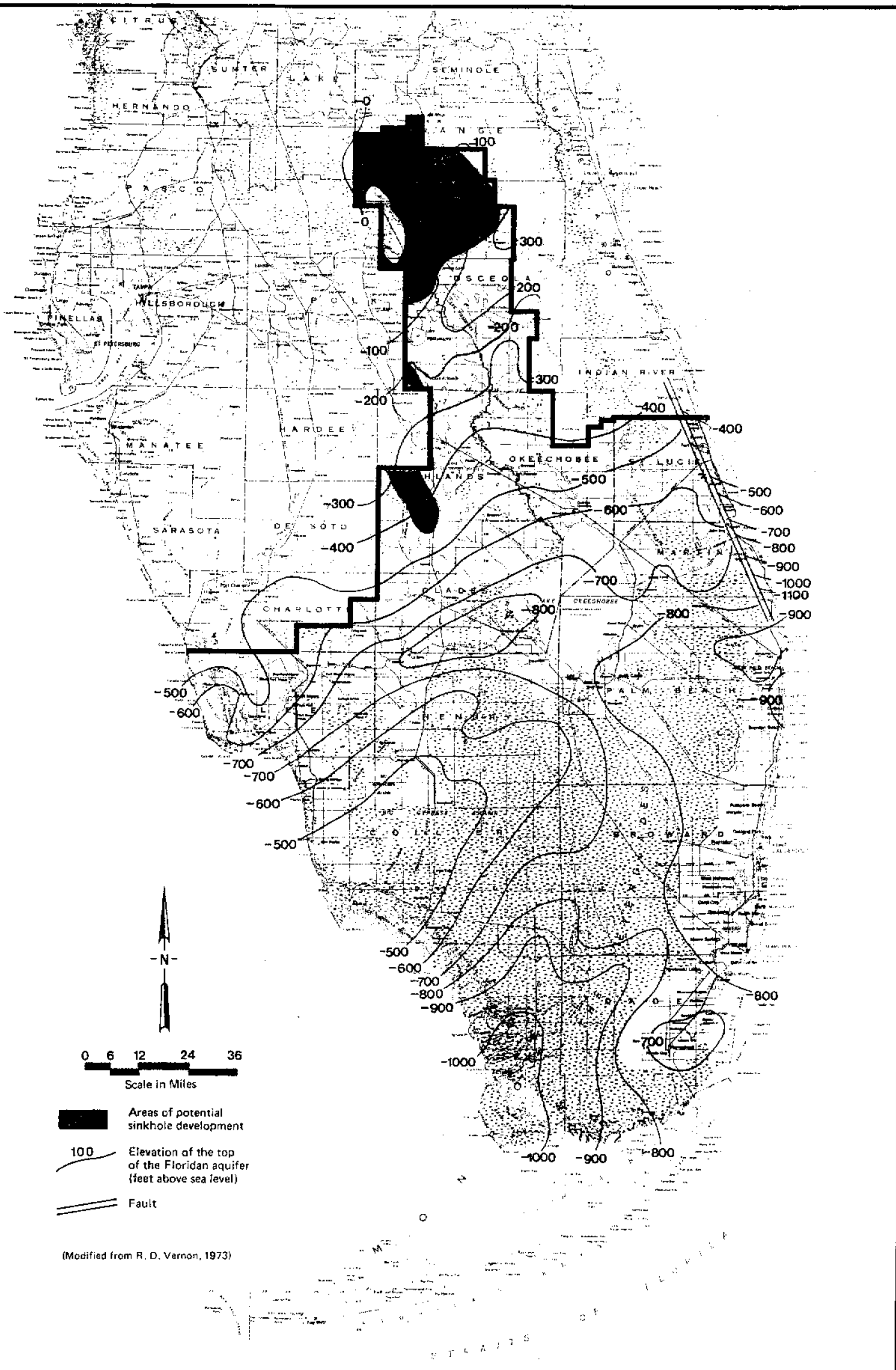


FIGURE 18. TOP OF FLORIDAN AQUIFER AND AREAS OF POSSIBLE ACTIVE SINKHOLES, SFWMD

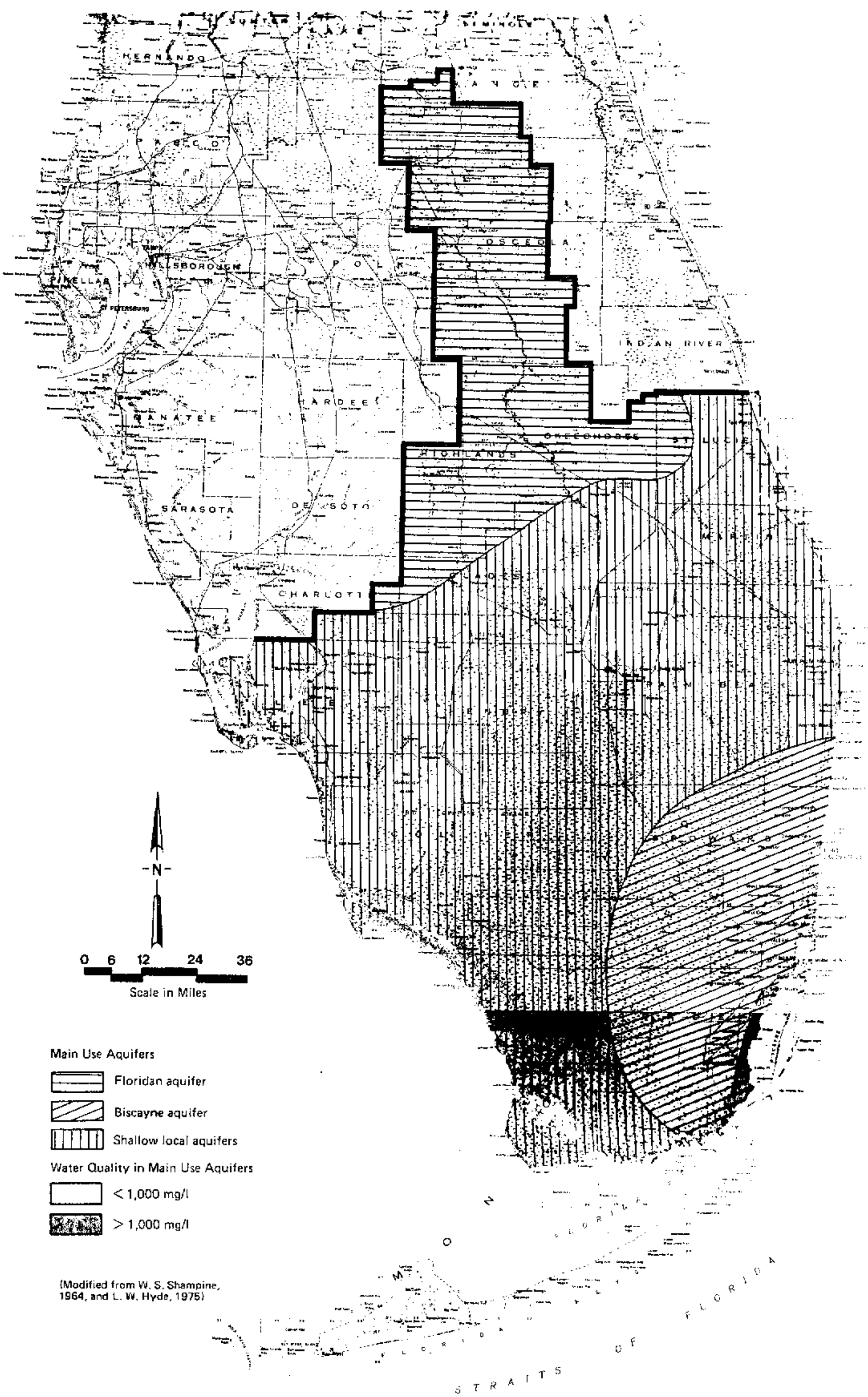


FIGURE 19. MAIN USE AQUIFERS AND WATER QUALITY, SFWMD

approximation of the quantity of water available in the upper east coast planning area.

Quality Of Feed Water: Table 6 presents the water quality from a few selected wells in south Florida. It depicts the total dissolved solids to be 1126 mg/l in Martin County. The Palm Beach County well had 4,875 mg/l TDS. Chloride content of the Floridan aquifer water ranges from 450 for Martin County to 2210 mg/l for Palm Beach County. These figures are regional and provide a general picture of the water quality of the area. On a localized scale however, the TDS of the feed water varies from one location to another, even in the same county.

Presented in Table 7 is the ion composition of selected brackish water wells which provide feed water for RO plants. Table 7 depicts the TDS variation from 1234 mg/l to 8541 mg/l in the District area. Low pressure membranes will not be able to desalt the 8541 mg/l TDS; therefore, the type of membrane capable of removing the particular TDS from water from a well should be selected.

Source Reliability: Water table aquifers from which the majority of water is withdrawn in south Florida are showing signs of stress due to excessive pumpage. This excessive pumpage has caused unacceptable head declines and salt water intrusion during droughts.

TABLE 6. TYPICAL WATER QUALITY FROM FLORIDAN AQUIFERS IN SOUTH FLORIDA

	Total Dissolved Solids	Calcium as Ca	Magnesium as Mg	Sodium as Na	Chloride as Cl	Sulfate as SO_4	Bicarbonate as HCO_3	Hardness as $CaCo_3$
Dade County well near Cutler Ridge	2,396	118	65	702	1,070	286	226	621
Martin County well near Indiantown	1,126	82	52	250	450	182	169	418
Palm Beach County well near Belle Glade	4,875	144	138	948	2,210	750	151	1,120

Note: Values in mg/l.

TABLE 7. IONIC COMPOSITION IN MG/L OF SELECTED WELLS WHICH SUPPLY FEED WATER TO RO PLANTS IN FLORIDA

Constituent	Rotunda West	Venice	Cape Coral	Rock Harbor	Key West	Sanibel
Chloride	3870	850	403	3999	3200	570
Sodium	NA	475	216	2421	1920	90
Sulfate	385	1500	112	720	752	450
Magnesium	272	75	69.7	386	170	127
Calcium	272	440	51.8	240	200	122
Bicarbonate	183	NA	NA	214	220	203
Carbonate	0	NA	NA	0	NA	0
Iron	.01	.20	.03	.6	1.2	.01
Silica	NA	NA	20.5	19	10	16
Hardness as Calc. Carbonate	150	160	211	1580	NA	826
TDS	7000	3600	1234	8541	6604	3400

The District imposes cutbacks on production during severe drought periods. The intention of these cutbacks is to prevent salt water from intruding into the well fields. Additionally, as stated earlier, extra quantities of water from this source may not be available in the future.

In recent times, Floridan aquifer wells were drilled and used mostly for agriculture. Agriculture needs large volumes of water for irrigation, but can use water with higher salt content than drinking water. Usually, Floridan aquifer wells yield more water than water table aquifers. Most of these wells were drilled improperly without any hydrogeologic testing. Due to rapid land use changes, a majority of these wells were abandoned.

The majority of the Floridan aquifer wells are free-flowing, waste valuable resources, and contaminate the water table aquifers. To protect water resources as well as to improve the quality of the surficial water, the District has initiated a well plugging program. The District cooperates with local Governments in plugging these free-flowing wells.

The passage of the Water Resources Act of 1972 places strict regulation on well construction. Properly constructed wells, at proper depths with special casings, can be reliable long term sources of water in the Floridan aquifer zone.

At one time, most of the wells in the Floridan aquifer were steel-cased. This created a clogging of membrane elements due to casing corrosion. Most of the steel cased agricultural wells corroded and were abandoned. Wells are no longer steel cased because of this problem. An adequate testing program is therefore necessary to avoid expensive problems which arise later due to design mistakes.

Brine Disposal:

Reject water from desalination plants must be disposed of properly. These reject brines vary in TDS from 10,000 to 20,000 mg/l from brackish water RO plants. Direct discharge of the brine into fresh water stream bodies without additional treatment cannot be made, as it degrades the quality of the receiving water bodies. Injection of brine into saline underground aquifers is ideal, provided the cost is not prohibitive.

PRESENT RO TECHNOLOGY - LOWER NET PRESSURE MEMBRANES

In the past, Reverse Osmosis membranes were designed and operated for high membrane water flux. They were also designed for desalting performance at 400 psi net driving pressure (NDP). The system feed pressures needed for these membranes were in the range of 400-600 psi for brackish waters. System feed pressures varied between 800-1000 psi for sea water situations. Energy required to boost the pressure of feed water to operating pressure in RO processes represents the largest portion of the operating costs.

There are now several low pressure membranes available on the market. (Table 1) These membranes require less net driving pressures than the older membranes. (Table 2) A low pressure membrane, in essence, is a high flux membrane. This membrane is capable of producing water of a quality and quantity comparable to that of a high pressure membrane. The logical approach to achieve this is to increase permeate flow rate through a membrane. A membrane polymer with a higher water permeability coefficient and/or a thinner mem-brane produces high flux. Additionally, this same membrane must also provide an acceptable quality. Brackish water containing 5,000 TDS at high recovery requires a rejection rate of at least 95%.

Dow introduced the first new hollow, fine fiber membrane that efficiently operated at transmembrane pressures of approximately 16 atmospheres (250 psi), and now all the manufacturers are producing these low pressure membranes. These membranes have the above stated flux and salt rejection characteristics. These membranes are now used commercially where the TDS of the raw water is between 4000 to 5000 mg/l. (Tables 1 and 2)

Literature reports that potential savings of a low pressure membrane can be 30-50% in operating costs alone. This saving is due to lower energy requirements. An additional 5-15% saving is realized in system capital costs in terms of lower pressure rated housings, piping, hardware, and smaller pumps (12).

In 1983, Venice, Florida installed the world's largest low pressure Reverse Osmosis plant. This RO plant had the capacity to desalt 1 million gallons of water a day.

In mid-1984, Cape Coral replaced its 5 MGD standard Dupont and Dow Membranes for Dow's low pressure membranes. The changeover took place in less than a month. It made the city the world's largest low pressure installer at that time. In late 1984, Cape Coral expanded the facility with an additional 7 MGD of low pressure spiral membranes. These membranes were manufactured by Hydra-nautics. Another 7 MGD low pressure membrane RO plant is being planned for the near future.

Sanibel Island is also moving towards installation of low pressure membranes for its potable water supplies. Basic Technologies, Inc., installed the first 0.5 MGD low pressure RO plant in 1986.

Most of the recent low pressure RO plants are micro-processor controlled. These microprocessors permit the careful regulation of flows, chemical additions, start ups, and shutdowns based on programmed parameters without manual intervention, as needs arise. Microprocessors provide high reliability and lower operation costs.

MEMBRANE PROCESS FOR OTHER USES

Membrane Softening

Presented in Figure 20 is the filtration spectrum. This graph shows the capacity of various treatment processes to remove common materials found in our drinking water. In the past, RO membranes were used strictly for desalination.

With the development of various kinds of membranes, different uses are being explored. There is a growing trend to use membrane softening in lieu of lime softening. These membranes are "loose" membranes, and operate at 100 psi or below on high hardness well water.

Post, Buckley, Schuh and Jernigan, Inc., (in south Florida) ran a successful pilot test at Boynton Beach. This test compared membrane softening versus lime softening. William Conlon, P.E. of the aforementioned firm, points out the membrane softening advantages over lime softening, as follows:

1. The ability to produce higher quality water (elimination of organic chemicals and THM's as well as conventional softening),
2. Reduced spatial requirements (a 10:1 reduction in land area needs),
3. Lower investment requirements,
4. No sludge disposal requirements,
5. No lime storage requirements,
6. Ease of expansion through use of modular units,
7. Better site aesthetics,
8. Automatic processing and shutdown capability, and
9. Potential cost savings.

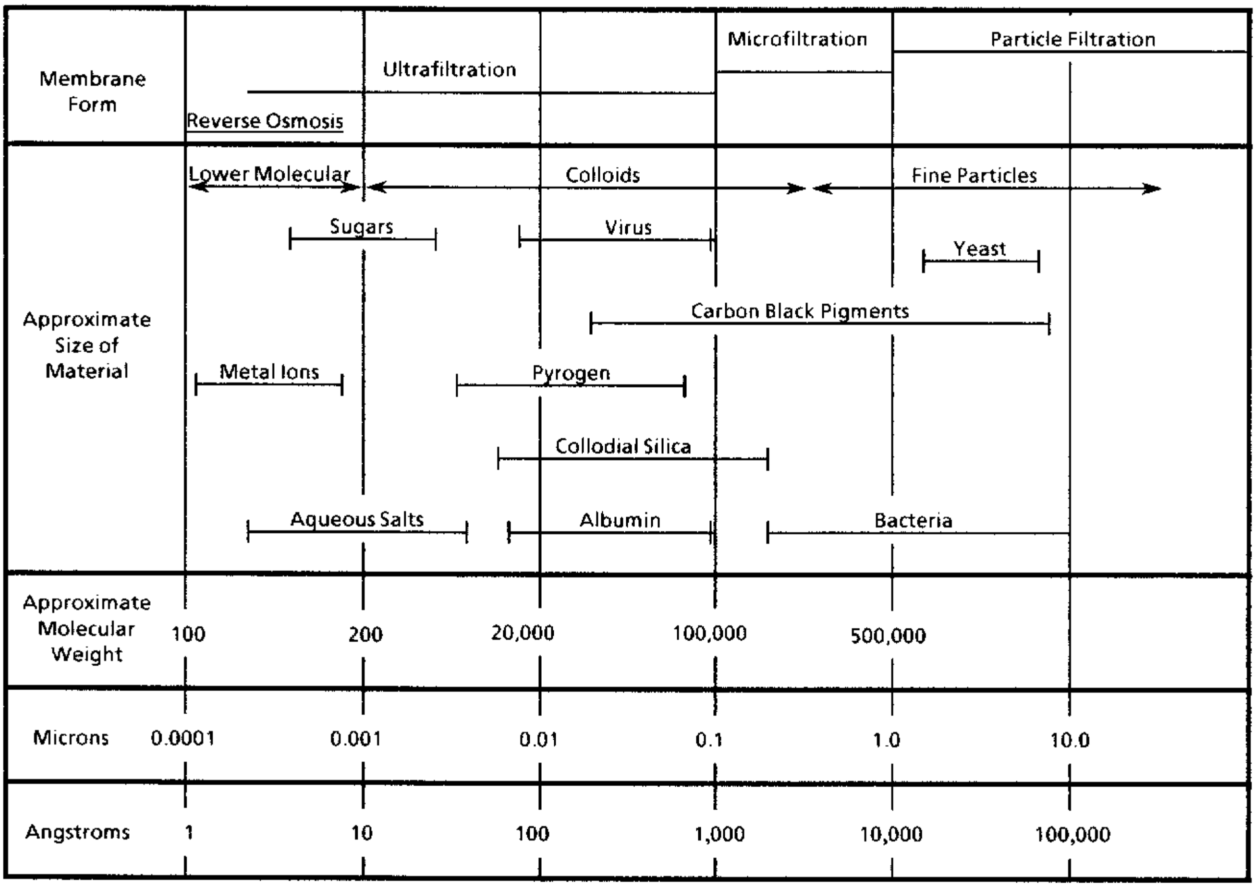


FIGURE 20. FILTRATION SPECTRUM

DSS Engineers, Inc., (unpublished report) recently completed a feasibility study on membrane versus lime softening for a Florida client. This study consisted of developing preliminary capital and operating costs for membrane softening RO and comparing them with conventional lime softening. DSS Engineers made the following assumptions in their study.

a)	Plant factor	75%
b)	Reverse Osmosis Recovery	80%
c)	Land costs	$25,000 per acre
d)	Indirect costs	25%

The above costs included the following:

Site development
Wells and supply piping
Building
Reject system (pipe length one mile)
Aerator for reject stream
Pre- and post-treatment equipment
Ground storage tanks
High service pumps

The costs for lime softening did not include extras for air stripping and carbon adsorption necessary for the removal of organic contaminants (Table 8).

Table 8 depicts the advantage of mem-brane softening over lime softening. Even though the pilot scale studies show the advantage of this method, so far no large scale plants have been installed.

WASTEWATER RECLAMATION

Hoover Dam: Reverse Osmosis is being tested for its capacity to remove nutrients from reclaimed water at various locations. RO's capacity to remove nutrients from reclaimed water underwent a rigorous testing at Hoover Dam during a six month period. Feed water to the RO membrane was wastewater generated by many tourists and employees. This pilot study found PO4 concentration in the final blended effluent to be 95% lower than in the RO feed. NH3-N concentration in the final blended effluent was reduced by 77%. Previously, NH_3-N removal by RO membranes was reported to be only 60% (11).

The second test consisted of the same methods as treatment 1, except the feed water received biological treatment before lime treatment. The biological treatment plant was a typical coarse bubble, diffused, activated sludge plant. The average detention time in the aeration tank was approxi-mately 10 hours, and the mean cell residence was approximately 20 days.

Nutrient concentrations monitored during this phase of operation again included total phosphate PO_4, ammonia-nitrogen(NH_3-N) and nitrate nitrogen (NO_3-N). Concentrations of PO_4, NH_3-N, and NO_3-N were reduced by 99, 84, and 79 percent respectively.

This study demonstrates the utilization of RO as an effective means of treating sanitary waste. RO as reported is capable of removing dissolved minerals and contaminants not possible with conventional means.

The above tests concluded that RO membranes can reduce significant percentages of Phosphorus and Nitrogen (1).

Water Factory 21: Orange County Water District (OCWD) also has been conducting tests with different membranes. These tests are conducted to determine the amount of pretreatment that is necessary for operation of a large water treatment plant. The District wants to determine whether low pressure membranes can reduce the energy requirements of the large system.

TABLE 8. TOTAL COSTS VERSUS PLANT CAPACITY MEMBRANE AND LIME SOFTENING

Plant Capacity MGD	Costs, $/1000 gallons Lime Softening	Membrane Softening
0.5	2.05	1.60
1.5	1.60	1.15
2.5	1.30	1.00
3.5	1.18	0.96
4.5	1.02	0.90
5.5[1]	0.93	0.91

[1]Beyond 5.5 MGD, membrane softening cost is only slightly lower than conventional lime softening.

Water Factory's test facility for new membrane elements consists of two 10,000 gpd RO units. The feed water is municipal secondary effluent that has passed through lime softening and clarification steps. The ammonia stripping, recarbonation, multimedia depth filtration, and carbon adsorption were bypassed. This feed water contained approximately 1,000 mg/l TDS, along with organic and biological matter. This is a relatively poor quality feed water for RO processing. FilmTec elements were installed in this system in late January 1981. The system operated at 70 percent recovery at a pressure of 250 psi. These elements, tested at FilmTec, had exhibited over 20 gfd membrane flux on a 0.2 percent salt solution at 200 psi.

However, at OCWD the elements initially provided only 10-12 gfd at a pressure of 250 psi. The flux was reduced to 7.5-9 gfd after 5,000 hours. The salt rejection was excellent, being between 96 and 97 percent and the product water conductivity was 30 micromohs per centimeter. Membranes were cleaned using a combination of one percent each of trisodium phosphate, EDTA, and sodium tripolyphosphate. The flux showed a gradual downward trend between cleanings. Flux recovered after each cleaning operation. The membranes were cleaned once a week. Investigation of the membrane elements showed strong evidence of biological fouling.

Non-ionic and cationic surfactants were suspected in the water. Some of these surfactants reduce the flux in the FT-30 membranes.

It is quite likely that the ammonia in the feed water had converted all the chlorine to chloramine. Chloramine is not damaging to the FT-30 membrane. The tests at Orange County confirm that the FT-30 membrane is very rugged. To restore the flux, FT-30 membranes need regular cleaning (13).

Recently a new test has started with two banks of BW30-4021 elements feeding into another bank of the same elements. The test is again being run at 250 psi. The initial flux was 14 gfd, but dropped to 10 gfd after 730 hours. Some shock chlorination experiments were performed. Even with injection of 25 mg/l of chlorine, FT-30 membranes were not damaged.

ORGANIC CONTAMINANT AND THM REMOVAL BY RO PROCESS

Recent studies conducted by the U.S. EPA and others have documented the actual or potential contamination of our nation's ground water.

This contamination threat is wide scale. Studies conducted in the state of Florida have also documented the potential of contamination of its ground water. In Florida, ground water contamina-tion can be both organic and by salt water intrusion. In addition, THM is found in most of the utility supplied drinking water (5). This precursor develops when free chlorine reacts with the humus and the humic acid found in Florida waters. Conventional treatment alone cannot remove this precursor. The Florida Senate's Committee on Natural Resources investigation revealed that water quality was the most pressing problem during the 80's. Presently, state-wide ground water wells are being monitored for organic contamination.

The most desirable way to control ground water contamination is to prevent pollution from taking place. Such pollution prevention plans already exist in Florida. For those wells or well fields already contaminated, various remedial processes exist. From a strictly economic point of view, these contaminated aquifers (with treatment) can still provide the cheapest water supply to the communities they serve.

EPA has conducted extensive research into the development of treatment technologies for removing both inorganic and organic contaminants from ground water. Lately this effort has emphasized the removal of volatile organic compounds (VOCs) and synthetic organic chemicals (SOCs) such as pesticides.

An EPA report states that carbon adsorption is effective for removing both VOCs and SOCs. Carbon adsorption is also effective in removing THMs(14). Packed tower and diffused aeration were also found to be best suited for removing both VOCs and SOCs. EPA is testing on the bench and pilot scale various other methods for VOCs and SOCs removal. These methods are ozone treatment, RO, Ultra Violet, etc. All the field studies conducted by EPA also include cost and performance data as part of the data gathering.

Cost curves developed from previous studies were used to predict the most cost effective technologies for contaminants removal.

Presented in Table 9 are the treatment technologies for removing SOCs and VOCs. Costs associated with this treatment process is provided in the cost estimation section.

Table 9 clearly depicts that conventional treatment alone cannot remove the volatile and synthetic organic compounds in water. Therefore, to remove the organic contaminants, conventional

TABLE 9. TREATMENT TECHNOLOGIES FOR REMOVING SOCS & VOCS

Technology Status	Technology Description	Contaminants for which Technology is best suited
Field Tested	Carbon Adsorption	VOCs & SOCs
	Packed tower and Diffused-air aeration	VOCs
Promising Technologies	Conventional	SOCs
	Ozone Oxidation	VOCs & SOCs
	Reverse Osmosis	VOCs & SOCs
	Ultraviolet	VOCs & SOCs

PERFORMANCE SUMMARIES FOR TECHNOLOGIES EXAMINED

REMOVAL EFFICIENCY*

Regulatory Phase	Organic Compounds	Granular Activated Carbon Adsorption Filtrasorb 400a	Packed Tower Aeration	Reverse Osmosis Thin Film Composite	Ozone Oxidation (2-6 mg/l)	Conventional Treatment
VOLATILE ORGANIC COMPOUNDS						
	Alkanes					
I	Carbon Tetrachloride	E	E	E	P	P
I	1,2-Dichloroethane	E	E	A	P	P
I	1,1-Trichloroethane	E	E	E	P	P
I	1,2-Dichloropropane	E	E	E	P	P
II	Ethylene Dibrimide	E	E	E	P	P
II	Dibromochloropropane	E	A	NA	P	P
	Alkenes					
I	Vinyl Chloride	E	E	NA	E	P
II	Styrene	NA	NA	NA	E	P
I	1,1-Dichloroethylene	E	E	NA	E	P
II	cis-1,2-Dichloroe thylene	E	E	P	E	P
II	trans-1,2-Dichloro-ethylene	E	E	NA	E	P
I	Trichloroethylene	E	E	E	A	P
	Aromatics					
I	Benzene	E	E	P	E	P
II	Toluene	E	E	NA	E	P
II	Xylens	E	E	NA	E	P
II	Ethylbenzene	E	E	NA	E	P
II	Chlorobenzen	E	E	E	A	P
II	o-Dichlorobenzene	E	E	A	A	P
I	p-Dichlorobenzene	E	E	NA	A	P

TABLE 9. (Cont'd) TREATMENT TECHNOLOGIES FOR REMOVING SOCS & VOCS

	Pesticides					
I	Pentachlorophenol	E	P	NA	E	P
II	2,4-D	E	P	NA	A	P
II	Alachlor	E	E	E	E	P
II	Aldicarb	NA	P	NA	NA	NA
II	Carbofuran	E	P	E	E	P
II	Lindane	E	P	NA	P	P
II	Toxaphene	E	E	NA	NA	P
II	Heptachlor	E	E	NA	E	P
II	Chloradane	E	P	NA	NA	NA
II	2,4,5-TP	E	NA	NA	A	NA
II	Methoxychlor	E	NA	NA	NA	NA
	Other					
II	Acrylamide	NA	P	NA	NA	NA
II	Epichlorohydrin	NA	P	NA	P	NA
II	PCB's	E	E	NA	NA	NA

E - excellent 70 -100% removal
A - Average - 30- 69%
O - Poor - 0-29%
NA - Data not available or compound not yet tested by EPA.

methods require the addition of one of the above processes in series. Chlorine precursors, if any exist, are also removed by use of the above methods. Addition of one of the above processes, on line with the conventional methods, increases water production costs, however.

Membrane technology alone can be used instead of using carbon adsorption, packed tower, or diffused air aeration on line with conventional methods. RO serves a double purpose; 1) it removes organic contaminants, if any, and 2) can produce additional water. The cost of RO produced water is comparable to the cost of conventionally treated water, and is exclusive of the additional cost of one of the aforementioned methods.

COST ESTIMATES

This report provides three desalination cost estimates, two general and one specific to south Florida conditions, for comparison purposes. Cost estimates of removing organic compounds from the drinking water are also provided.

CASE I- General

Kremen et al., (12) provide a detailed cost evaluation for both the high and low pressure RO membranes. These membranes can treat brackish water in the range of 250, 350, and 450 psi. This study also includes temperature variation in the range of 15 to 35 degrees celsius, and compares membrane performance at initial and mid-span life span. Feed water recovery ranged from 30 to 87.5% from both standard and low pressure membranes.

This study provides the effect of various design parameters affecting the final cost. The report also includes the sensitivity analysis of parameters affecting the final costs of product water.

The following assumptions were made in the Kremen et al., cost/performance study.

1. Membrane and Element Characteristics - Spiral wound elements were assumed to be flat sheet membranes. These membranes were assumed to have a flux rate of 16 gfd. Fluxes were assumed to be the same (25 degrees) at 200 psi net (LP) and 400 psi net (SP), respectively, at 25 degrees celsius. Feed water was 2000 mg/l NaCl with 10 percent recovery.

Salt passage - An allowable salt passage of 4 percent, with 96 percent of chloride being rejected.

Each membrane had a life expectancy of 1095 days (3 years) at 100 percent availability.

2 Applied Pressure Ranges - The applied pressure ranges were 250, 350, and 450 psi. Systems were to

operate at constant pressure. Performance and membrane requirements were compared at Day 1 and Day 500 (mid-life).

3. Feed Water Temperature - The temperature of the feed water assumed was 15, 25, and 35 degrees celsius.

4. Water Flux Change Expectancies - ("m" values)

	P9(psi)	"m"
T(c) 15	250	-.009
T(c) 25	250	-.012
T(c) 35	250	-.018
T(c) 15	350	-.012
T(c) 25	350	-.016
T(c) 35	350	-.024
T(c) 15	450	-.018
T(c) 25	450	-.024
T(c) 35	450	-.036

5. Salt Passage Rate Change Expectancies - Salt passage was assumed to be increasing at an exponential rate and doubling every 1095 days. This is equivalent to an increase of 37% in 500 days (approximate mid-life)

$$C_{pt} = C_{p1}\,(2)^{t/1095}$$

where

C_{pt} is the permeate concentration at time "t",

C_{p1} is the Day 1 permeate concentration, and

"t" is the number of calender days following first use.

6. System Permeate Production and Feed Water Recovery Fractions. Permeate production was approximately 1 MGD at 50, 75, and 87.5 percent recoveries, respectively.

7. Feed Water Salinities

RAW FEED CONCENTRATION AND RANGES*

Constituent Concentration (mg/l)	1	2	3	4	5	6
Ca	30	60	120	140	140	140
Mg	25	45	90	96	96	96
Na	95	200	400	750	1596	2322
K	5	10	20	25	25	25
HCO3	92	180	360	400	400	400
SO4	79	160	320	360	360	360
Cl	165	330	660	1200	2415	3629
F	1	2	4	4	4	4
SIO2	6	12	24	24	24	24
TDS	498	999	1998	2999	5000	7000

*Feed water concentrations in Table 9 were assumed before the addition of H_2SO_4 to neutralize 75 percent bicarbonate alkalinity.

The foregoing hypothetical compositions were developed to simulate present and foreseeable major brackish RO commercial applications for the following;

a. To produce ultra pure water for semi-conductor manufacturing and high pressure boilers. These manufacturing procedures require super pure water. Even municipal supplies (less than 500 mg/l TDS) need further treating for these processes.
b. For water reclamation and demineralization of mildly brackish waters. Examples are Orange County Water District and Cape Coral waters which both have feed water TDS of 1000 mg/l. At this low feed water level, blending is possible depending on the desired product standards.
c. To desalt brackish well waters from 1500-7500 mg/l TDS, Sarasota, Ocean Reef, and Florida Keys (Rock Harbor) have native water TDS in the range of 1500-7500 mg/l.

In the above hypothetical feed compositions, salinities in excess of 2000 mg/l were assigned to NaCl.

Membrane Replacement Costs (Spiral Wound). The following prices were used in the analysis.

LP elements - 5330 gpd - $1000
SP elements - 5330 gpd - $800

Replacement costs were estimated to be one third of the membrane cost divided by the number of kilogallons of permeate produced annually.

Pressure Vessels - Initial and Amortization Costs (Spiral Wound). A pressure tube containing 6 elements, each 8" x 40", would be approximately 8" diameter and 21 feet long. The cost of this vessel, complete with fittings (part of the rack, frame, and manifold piping) was estimated at $2500. This was amortized at 20 percent, or $500 per year. This cost was distributed to the number of kilogallons per year produced by the elements in that vessel.

Power Requirements and Costs Power costs were arbitrarily set at $0.10 per kilowatt-hour. Power usage (E) in kilowatt hours, required to produce 1 kilogallon of RO permeate, was calculated using the formula:

$$E = 7.323 \times 10^{-3} \times P \,/\, R \times e$$

where,

P is the applied pressure in psi.
R is the recovery fraction, and
e is the combined pump and motor efficiency fraction.

e is the combined pump and motor efficiency fraction.

The efficiency of the equipment is heavily dependent on the type of pump and the method of pressure control. For this study, pump and motor efficiencies were assumed to be 100 percent.

RESULTS FROM THE STUDY

Table 10 presents the cost of producing 1000 gallons of product water from 1000 TDS feed water at various recovery efficiencies. Table 10 also shows the various components of production costs. As expected, at higher efficiencies the price of water goes down. It costs $1.29 to produce 1000 gallons of product water at 50 percent efficiency; however, at 75 percent efficiency, the production cost reduces to $1.07.

For 5000 TDS feed water, it costs $1.54 to produce 1000 gallons of product water at 50 percent recovery efficiency. This production cost reduces to $1.50 at 75 percent recovery efficiency; however, when the plant operates at 87.5 percent efficiency, the production cost increases to $1.74 (Table 11). Figures

TABLE 10. CAPITAL AND OPERATING COST SUMMARY

TDS 1000 MG/L AGE 500 DAYS TEMP 25° CELSIUS

RECOVERY %	50.0	50.0	50.0	75.0	75.0	75.0	87.5	87.5	87.5
MEMBRANCE PRESSURE	250.0	350.0	450.0	250.0	350.0	450.0	250.0	350.0	450.0
CAPITAL COST (US$/DAILY GAL)									
PRETREATMENT	.076	.076	.076	.072	.072	.072	.069	.069	.069
H.P.Pumps	.060	.063	.071	.041	.045	.050	.040	.043	.049
VESSELS	.067	.048	.077	.071	.051	.082	.075	.054	.081
MEMBRANE	.174	.126	.161	.185	.133	.172	.195	.141	.170
SUB-TOTAL	.377	.314	.385	.368	.301	.376	.379	.306	.369
LABOR SYS-ASSY	.077	.077	.077	.072	.072	.072	.070	.070	.070
VES-ASSY	.012	.008	.014	.012	.009	.015	.013	.009	.014
TOTAL DIRECT	.466	.399	.476	.453	.382	.463	.462	.386	.453
GROSS MARGIN	.155	.133	.159	.151	.127	.154	.154	.129	.151
SYSTEM PRICE	.621	.533	.635	.603	.509	.618	.616	.514	.605
INSTALLATION	.093	.080	.095	.091	.076	.093	.092	.077	.091
INSTALLED COST	.714	.612	.730	.694	.586	.710	.709	.591	.695
OPERATING COSTS (IN US$/KGAL OF PERMEATE)									
FIXED CHARGES	.391	.336	.400	.380	.321	.389	.388	.324	.381
MEMBRANE COSTS	.159	.115	.147	.169	.122	.157	.178	.128	.155
POWER	.448	.619	.796	.314	.434	.551	.269	.372	.472
OPER. & MAINT.	.230	.230	.230	.210	.210	.210	.200	.200	.200
WATER COST	1.23	1.30	1.57	1.07	1.09	1.31	1.04	1.02	1.21
ADJUSTED COSTS (COST/TDS RED.)	1.29	1.34	1.66	1.15	1.14	1.41	1.14	1.09	1.34

TABLE 11. CAPITAL AND OPERATING COST SUMMARY

TDS 5000 MG/L — AGE 500 DAYS — TEMP 25° CELSIUS

RECOVERY %	50.0	50.0	50.0	75.0	75.0	75.0	87.5	87.5	87.5
MEMBRANCE PRESSURE	250.0	350.0	450.0	250.0	350.0	450.0	250.0	350.0	450.0
CAPITAL COST (US$/DAILY GAL)									
PRETREATMENT	.076	.076	.076	.072	.072	.072	.069	.069	.069
H.P.Pumps	.060	.063	.071	.041	.045	.050	.040	.043	.049
VESSELS	.087	.058	.088	.104	.066	.096	.128	.075	.105
MEMBRANE	.228	.151	.185	.271	.171	.200	.334	.197	.219
SUB-TOTAL	.452	.348	.421	.487	.353	.417	.572	.384	.442
LABOR SYS-ASSY	.077	.077	.077	.072	.072	.072	.070	.070	.070
VES-ASSY	.015	.010	.016	.018	.012	.017	.023	.013	.018
TOTAL DIRECT	.544	.436	.513	.578	.437	.507	.664	.467	.530
GROSS MARGIN	.181	.145	.171	.193	.146	.169	.221	.156	.177
SYSTEM PRICE	.726	.581	.684	.770	.583	.676	.885	.623	.707
INSTALLATION	.109	.087	.103	.116	.087	.101	.133	.093	.106
INSTALLED COST	.835	.668	.787	.886	.670	.770	1.020	.717	.813
OPERATING COSTS (IN US$/KGAL OF PERMEATE)									
FIXED CHARGES	.457	.366	.431	.485	.367	.426	.558	.393	.445
MEMBRANE COSTS	.208	.138	.169	.248	.157	.183	.305	.180	.200
POWER	.448	.619	.796	.314	.434	.551	.269	.372	.472
OPER. & MAINT.	.300	.300	.300	.260	.260	.250	.250	.250	.250
WATER COST	1.41	1.42	1.70	1.31	1.22	1.42	1.38	1.19	1.37
ADJUSTED COSTS (COST/TDS RED.)	1.54	1.50	1.85	1.50	1.33	1.61	1.74	1.36	1.64

21-23 present the cost in $ per 1000 gallons of product water for various feed water recoveries.

The cellulosic hollow fiber membrane system water production cost, as the study shows, is lower than the previous one. The report cites that these cost figures came directly from the membrane manufacturer (Dow Chemical). Costs for various feed water TDS are presented in Tables 12 and 13. These production costs are much lower than the spiral membranes.

CASE II- South Florida Specific

DDS Engineers provide the site specific cost estimates for different size RO plants in south Florida. DSS prepared the following cost estimates for the Corps of Engineers South Florida Water Supply Study (Table 14). Several assumptions were made in the study to arrive at the final cost figures. Assumptions made to calculate the unit operating and the production costs are as follows (4 &5).

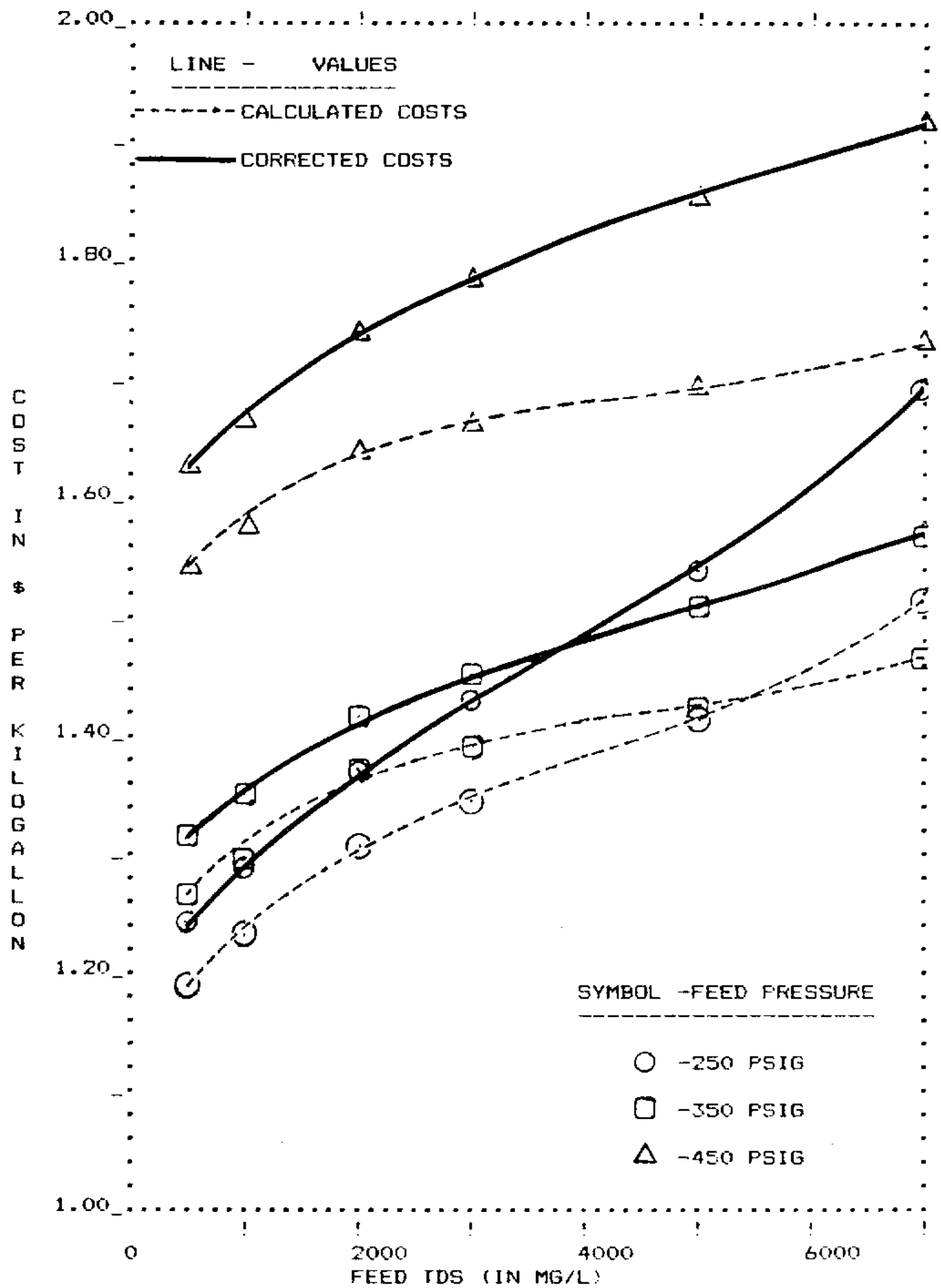


FIGURE 21. COMPARISON OF COSTS VS FEED TDS - 50% RECOVERY

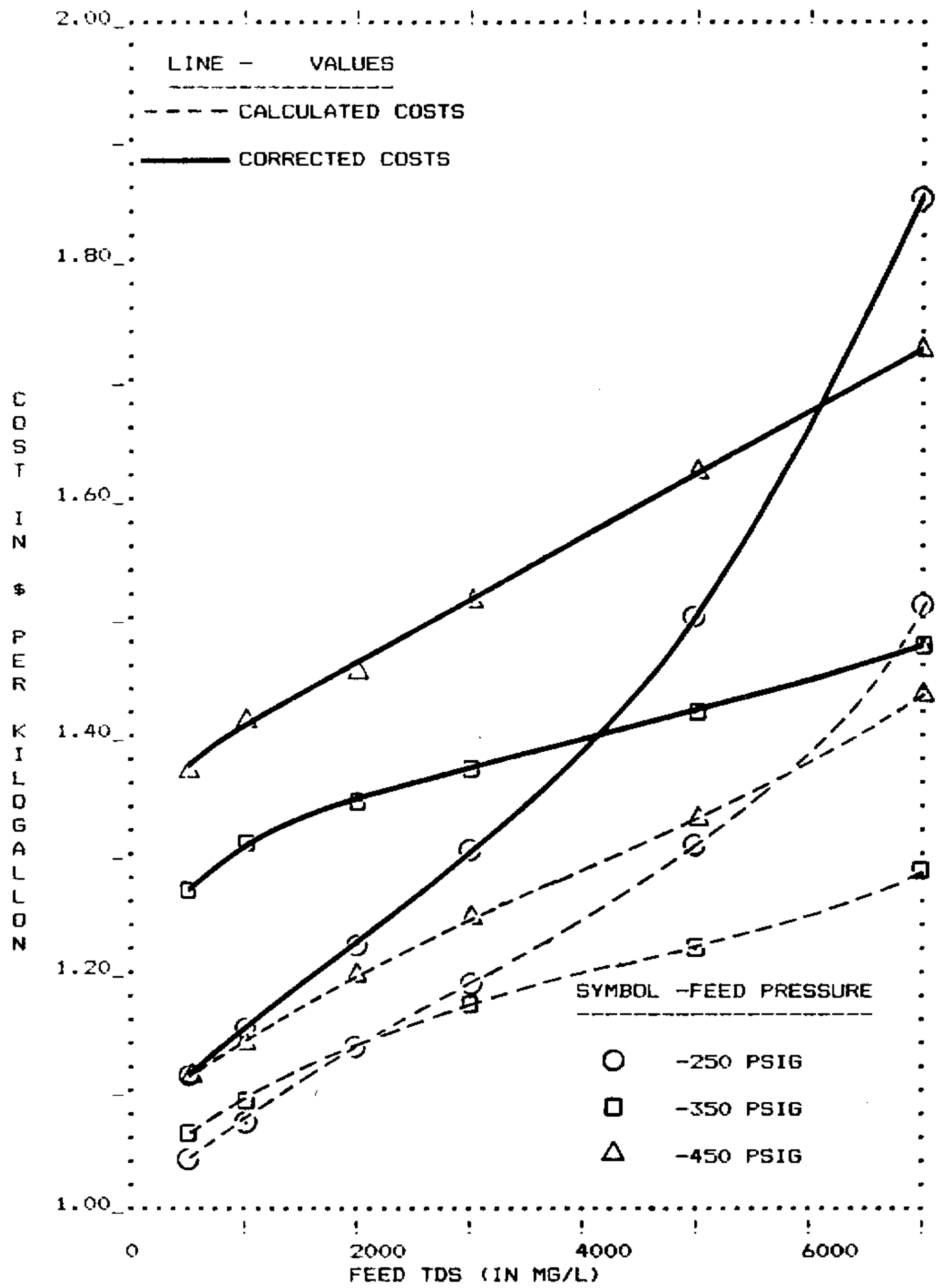


FIGURE 22. COMPARISON OF COSTS VS FEED TDS - 75% RECOVERY

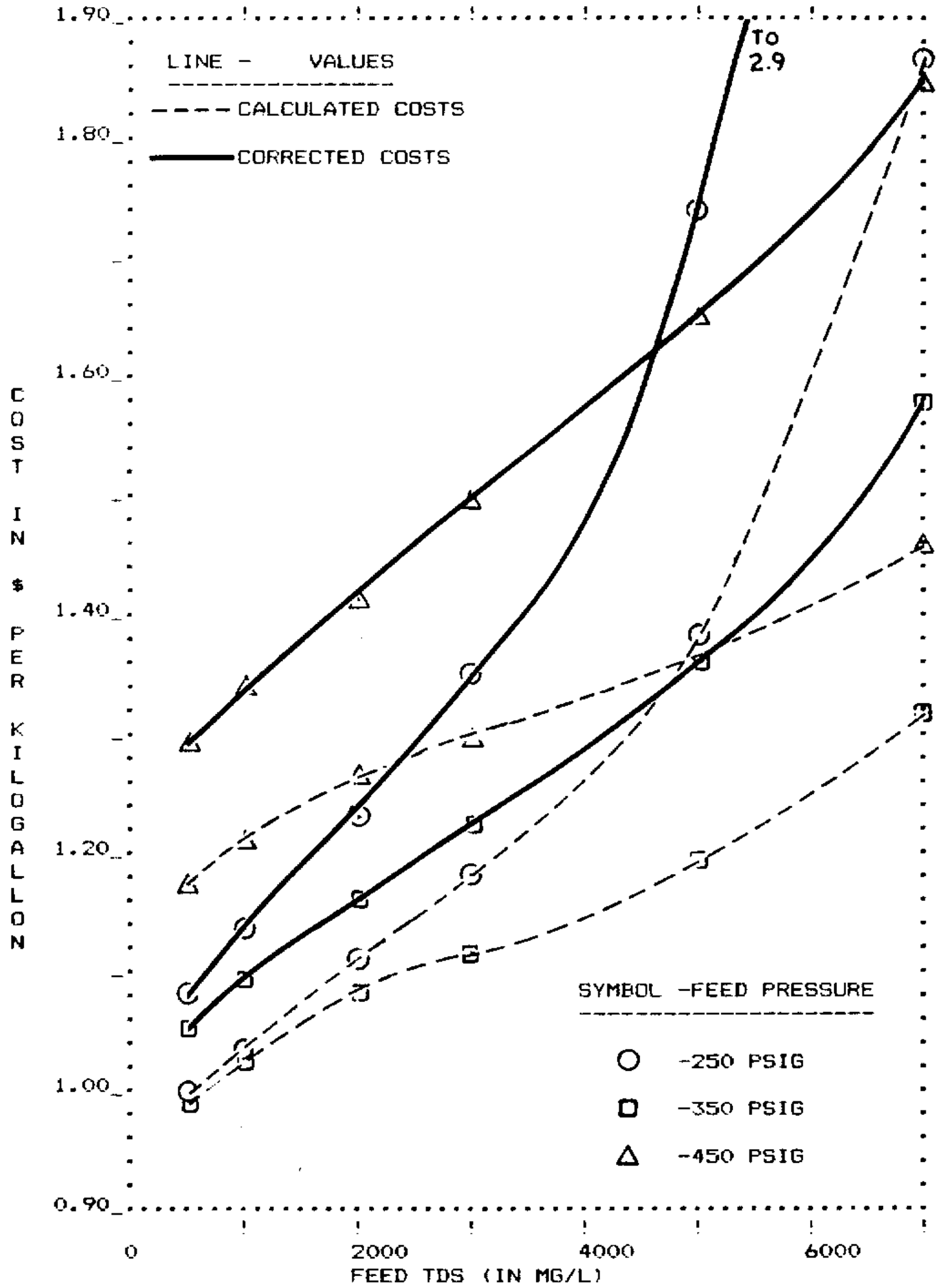


FIGURE 23. COMPARISON OF COSTS VS FEED TDS - 87.5% RECOVERY

TABLE 12. SPIRAL MEMBRANE SYSTEMS - 1 MGD PERMEATE PRODUCTION PROJECTED BRACKISH WATER REVERSE OSMOSIS CONDITIONS, PERFORMANCE, AND COSTS

FEED TDS mg/l	Per Cent Recovery	Pressure (psig)	Mem-brane Type	No. of Ele-ments	No. of Pressure Vessels	Gal. Per Ft.2 Per Day	Permeate TDS (mg/l)	Power Use (KwHr/KGal)	Water Costs (USD/KGal) Calc*	Corr**
1000	50	250	LP	174	29	17.2	47	4.5	1.23	1.29
	50	350	LP	126	21	23.9	34	6.2	1.30	1.34
	50	450	SP	198	33	21.8	54	8.0	1.57	1.66
	75	250	LP	180	30	16.2	66	3.1	1.07	1.15
	75	350	LP	126	21	22.5	48	4.3	1.09	1.14
	75	450	SP	216	36	14.5	74	5.5	1.31	1.41
	87.5	250	LP	210	35	15.4	90	2.7	1.04	1.14
	87.5	350	LP	126	21	21.4	64	3.7	1.02	1.09
	87.5	450	SP	210	35	14.1	98	4.7	1.21	1.34
5000	50	250	LP	228	38	13.2	409	4.5	1.41	1.54
	50	350	LP	150	25	19.9	271	6.2	1.42	1.50
	50	450	SP	228	38	13.0	414	8.0	1.70	1.85
	75	250	LP	270	45	11.1	648	3.1	1.31	1.50
	75	350	LP	162	27	17.5	410	4.3	1.22	1.33
	75	450	SP	288	48	12.0	598	5.5	1.42	1.61
	87.5	250	LP	294	49	9.0	1028	2.7	1.38	1.74
	87.5	350	LP	210	35	15.3	605	3.7	1.19	1.36
	87.5	450	SP	294	49	9.2	842	4.7	1.37	1.64

CONDITIONS - Feed Temperature: 25°C; Membrane Age: 500 Days
* Sum of Costs for membrane replacement, power, fixed charges, and O & M
** Above Costs divided by system feed TDS reduction fraction

TABLE 13. CELLULOSIC HOLLOW FIBER MEMBRANE SYSTEMS - 2 MGD PERMEATE PRODUCTION PROJECTED BRACKISH WATER REVERSE OSMOSIS CONDITIONS, PERFORMANCE, AND COSTS

FEED TDS (mg/l)	Feed Pressure (psig)	M Membrane Type	Number of Permeators	Permeate TDS (mg/l)	Power Use (kw-hr)	Selected Costs (USD/kgal) Calc*	Corr**
500	250	LP	99	16	3.2	0.56	0.58
500	350	LP	78	11	4.5	0.64	0.66
500	400	SP	96	11	5.2	0.74	0.76
2000	250	LP	108	84	3.2	0.59	0.61
2000	350	LP	84	52	4.5	0.66	0.67
2000	400	SP	105	60	5.2	0.76	0.79
5000	250	LP	189	494	3.2	0.78	0.87
5000	350	LP	117	251	4.5	0.74	0.78
5000	400	SP	141	223	5.2	0.85	0.89

Conditions: 75 percent recovery; 25° Celsius; Membrane age - 500 days
* Sum of projected costs for module replacement and power.
**Above codsts divided by system feed TDS reduction fraction

TABLE 14. LOW PRESSURE BRACKISH WATER RO (250 PSIG) DESALINATION COSTS FOR FEED WATER TDS OF UP TO 5000 MG/L WITH 80% RECOVERY (21) (COSTS IN $1000'S)

PLANT CAPACITY (MGD)					
ITEM	1	3	5	10	25
Construction Period (months)	6	9	9	12	15
DIRECT CAPITAL COSTS					
Basic Plant Equipment Installed	690	1897.5	2990.0	5850.0	14375.0
Facilities-Site Dev.	163.3	294.4	391.0	570.4	944.2
Feed Water Supply-Brine Disposal	96.6	231.8	322.0	515.2	1030.4
Electric Utilities Switchgear	172.5	436.1	612.7	1041.9	2208.0
Contractor Engr. OH & Profit	420.9	1072.4	618.4	2991.6	6959.1
Contingency(10%)	154.3	393.2	593.4	1096.9	2551.7
SUBTOTAL DIRECT COSTS	697.6	4325.4	6527.5	12066.0	28068.4
DIRECT COSTS($/GPD)	$1.70	$1.44	$ 1.31	$1.21	$1.12
INDIRECT CAPITAL COSTS					
Interest during construction	20.1	76.6	115.7	285.1	828.9
Working Capital	39.6	101.1	159.7	299.9	711.3
Owners Costs- A&E Fee(6%)	101.9	259.5	391.6	724.0	1684.1
SUBTOTAL - INDIRECT COSTS	161.5	437.2	667.1	1308.9	3224.3
TOTAL CAPITAL COSTS	1859.2	4762.7	7194.6	13374.9	31292.7
CAPITAL COSTS($/GPD)	$1.86	$1.59	$1.44	$1.34	$1.25
PRODUCTION COSTS (ANNUAL)					
Fixed Charges (9.5%)	176.6	452.5	683.5	270.6	2972.8
Direct O&M Labor	51.4	81.5	102.9	127.1	163.4
Labor OH & G&A (40%)	20.6	32.6	41.2	50.8	65.4
Energy Costs	85.3	256.9	426.5	853.0	2132.5
Chemicals	29.3	87.9	146.5	293.0	732.5
Cartridge Filters and Media	2.0	6.0	10.0	20.0	50.0
Membrane Replacements	36.0	108.0	180.0	360.0	900.0
Replacement Parts and Maint.	8.5	21.6	32.6	60.3	140.3
TOTAL ANNUAL COSTS	409.7	1047.0	1623.2	3034.9	7156.9
TOTAL ANNUAL PRODUCTION @85%(KGAL)	310250	30750	1551250	102500	7756250
UNIT OPERATING COST (NO CAPITAL)	$0.75	$0.64	$0.61	$0.57	$0.54
TOTAL UNIT PRODUCTION COST	$1.3	$1.12	$1.05	$0.98	$0.98

Direct Capital Costs - Estimated for mid-1983 equipment supply and construction in south Florida. Capital cost excludes land purchases and storage and distribution of water costs. Capital costs included a 10 percent contingency for these items.

Indirect Capital Costs - The following items were included in this cost category:

1) Interest during construction - 7.875% annually on disbursed amounts. Considered as average of 30% of total direct capital costs for period of construction.
2) Working Capital - Two months of operating costs
3) An architect and Engineering fee equal to 6% of direct capital costs.

Production Costs:

1) Labor - 1983 direct labor rates for the operation and maintenance of the appropriate size plant
2) Labor overhead - 40% of direct labor costs
3) Chemicals - Unit costs for chemicals for mid 1983. These unit costs were applied to the required normal usage of each chemical for the average feed characteristics:

Chemical	Unit Costs $/lb
Antifoam	1.05
Sulphuric Acid	0.03
Polyphosphate	1.81
Sodium Hexametaphosphate	0.32
Potassium Permanganate	0.65
Caustic Soda (NaOH)	0.21
Sodium Sulfite	0.06
Sodium Bisulfite	0.88
Chlorine	0.14

Energy - Purchased electricity at $0.05/KWH

Membrane Replacements - In this cost analysis, a membrane replacement cost of 12% per year was assumed. The unit production cost is estimated at $0.016/kgal.

Cartridge filters and filter media - Based on two changes of cartridge filters per year and one change of filer media per year. The unit cost was estimated at $0.0063/kgal.

Replacement Parts and Maintenance Materials - Based on 0.5% of installed equipment costs per year.

Fixed Charges - A 50 year project life span was used with interest at 7.875% resulting in an annual charge of 8%. Insurance cost of 0.5% and 1.0% for major replacements were added to this cost. A fixed charge applied to the capital costs was 9.5%.

Plant Load Factors - A 50 year project life is used with interest at 7.875 percent resulting in an annual charge of 8 %. Added to this is 0.5% for insurance and 1.0% for major replacements for a total of 9.5% fixed charge applied to the total capital costs.

Capital Costs - were estimated for a "turnkey" design, construction, and start-up, and include the following:

1) Basic Plant Equipment - Installed (includes sub-contractors direct field labor and field overheads).
2) Site Development and Facilities - No administrative offices or maintenance facilities.

DSS Engineer's cost estimates show the production cost of 1000 gallons of water from a 1MGD plant to be $1.32. This cost estimate also shows the economy of scale. As the plant size gets bigger, the production cost goes down. DSS engineers estimated the production cost at 80 percent recovery efficiency.

CASE III - Estimates From Different Vendors

Table 15 shows cost figures submitted by different vendors for a 5MGD brackish water plant. All three cost estimates show that production costs can vary from one location to another. Additionally, cost calcu-lations differ from one vender to another. Many vendors leave out the essential design elements, and care should be taken to evaluate these cost proposals.

COST SUMMARY FOR SELECTED VOCs

In an earlier section it was stated that contaminants can be removed using aeration, carbon adsorption, etc. Additionally, these techniques can also be used to remove the THM precursors; but this additional cost is extra. Table 16 presents the cost figures prepared by the US EPA.

Table 16 depicts that conventional treatment alone cannot remove the volatile as well as the synthetic organic compounds in water. For the removal of these compounds, one of the above technologies must to be used in series with the conventional methods. It is also worthwhile to mention here that the chlorine precursors can also be removed by use of the above methods. However, this additional expense raises the production cost of water significantly.

TABLE 15. DESALTING COST ESTIMATES AS PROVIDED BY VARIOUS COMPANIES FOR A 5 MGD RO PLANT

Data Source	Du Pont	DSS	DSS	VB
Salinity (mg/l)	1478	3000	3000	4000
Temperature(F)	77	70	70	65
Conversion %	75	80	80	75
Brine Disposal	ns	ns	ns	Minimal
Building	ns	ns	ns	Extensive
Storage Facilities	no	no	no	yes
Dist. Facilities	no	no	no	yes
Indirect costs	no	yes	yes	yes
Contingency	no	yes	yes	yes
Capital Cost ($/gpd)	1.25	1.38	1.16	2.12
Load Factor	0.96	0.85	0.85	0.83
Actual Capital cost ($/GPD)	1.30	1.62	1.36	2.55
Capital Cost Date	1982	1985	1985	1981
O&M Cost ($/1000Gals)	0.62	0.72	0.61	0.98
Membrane Life, Years	8.3	8.3	8.3	3
Replace Membranes	0.10	0.12	0.12	0.20
Total O&M $/1000 Gals	0.72	0.84	0.73	1.18

NS - not Specified

TABLE 16. EPA ESTIMATED COSTS TO REMOVE VOCs AND SOCs (Cost/1000 Gals)

VOCs	Capacity mgd	ug/l	Percent removal	Tower aeration	Diffused-air-aeration	Carbon adsorption
Tri-chloro-ethylene						
	0.5	100	90	.273	.546	.868
	10	99	.287	.793	.918	
	1	99.9	.296	1.032	1.010	
	.1	99.99	.303	1.270	1.124	
	1.0	100	90	.182	.383	.637
	10	99	.191	.611	.679	
	1	99.9	.196	.850	.765	
	.1	99.99	.202	1.088	.867	
	10.0	100	90	.083	.207	.356
	10	99	.088	.403	.390	
	1	99.9	.093	.587	.458	
	.1	99.99	.099	.755	.543	
Tetrachloro-ethylene						
	0.5	100	90	.279	.637	.610
	10	99	.293	.935	.660	
	1	99.9	.302	1.228	.705	
	.1	99.99	.308	1.486	.805	

TABLE 16. EPA ESTIMATED COSTS TO REMOVE VOCs AND SOCs (Cont'd.) (Cost/1000 Gals)

VOCs	Capacity mgd	Capacity ug/l	Percent removal	Tower aeration	Diffused-air-aeration	Carbon adsorption
	1.0	100	90	.186	.460	.453
	10	99	.194	1.752	.502	
	1	99.9	.201	1.046	.548	
	.1	99.99	.206	1.296	.651	
	10.0	100	90	.085	.277	.197
	10	99	.091	.514	.224	
	1	99.9	.098	.726	.251	
	.1	99.99	.103	.905	.313	
1,1,1-Trichloro-ethane						
	0.5	100	90	.270	.502	1.445
	10	99	.289	.825	1.651	
	1	99.9	.307	1.421	1.945	
	.1	99.99	.332	2.572	2.605	
	1.0	100	90	.180	.348	1.396
	10	99	.192	.644	1.500	
	1	99.9	.205	1.234	1.801	
	.1	99.99	.230	2.313	2.402	
	10.0	100	90	.082	.176	.802
	10	99	.192	.644	1.500	
	1	99.9	.205	1.234	1.801	
	.1	99.99	.230	2.313	2.402	
Carbon tetra-chloride						
	0.5	100	90	.264	.428	.942
	10	99	.287	.531	1.021	
	1	99.9	.272	.600	1.132	
	.1	99.99	.280	.648	1.340	
	1.0	100	90	.176	.292	.703
	10	99	.181	.371	.775	
	.1	99.9	.184	.427	.940	
	.1	99.99	.186	.470	1.063	
	10.0	100	90	.081	.133	.408
	10	99	.083	.196	.467	
	1	99.9	.084	.247	.550	
	.1	99.99	.085	.286	.719	
Cis-1,2-Dichloro-ethylene						
	0.5	100	90	.284	.727	2.513
	10	99	.296	1.010	2.791	
	1	99.9	.304	1.281	3.153	
	.1	99.99	.310	1.572	3.511	

TABLE 16. EPA ESTIMATED COSTS TO REMOVE VOCs AND SOCs (Cont'd) (Cost/1000 Gals)

	Capacity					
VOCs	mgd	ug/l	Percent removal	Tower aeration	Diffused-air-aeration	Carbon adsorption
	1.0	100	90	.189	.547	2.156
	10	99	.196	.828	2.417	
	1	99.9	.202	1.098	2.760	
	.1	99.99	.208	1.379	3.099	
	10.0	100	90	.087	.350	1.735
	10	99	.093	.571	1.989	
	1	99.9	.099	.763	2.327	
	.1	99.99	.104	.966	2.660	
1,2-Dichloro-ethane						
	0.5	100	90	.276	.587	1.286
	10	99	.285	.749	1.465	
	1	99.9	.292	.901	1.748	
	.1	99.99	.297	1.054	2.322	
	1.0	100	90	.184	.415	1.015
	10	99	.190	.568	1.177	
	1	99.9	.194	.720	1.437	
	.1	99.99	.197	.871	2.980	
	10.0	100	90	.084	.237	.675
	10	99	.087	.368	.820	
	1	99.9	.090	.489	1.057	
	.1	99.99	.094	.603	1.566	
1,1-Dichloroe-thylene						
	0.5	100	90	.262	.406	.880
	10	99	.265	.448	.963	
	1	99.9	.270	.500	1.066	
	.1	99.99	.272	.531	1.243	
	1.0	100	90	.174	.274	.647
	10	99	.177	.307	.721	
	1	99.9	.180	.348	.814	
	.1	99.99	.181	.371	.977	
	10.0	100	90	.080	.121	.364
	10	99	.081	.144	.423	
	1	99.9	.082	.176	.499	
	.1	99.99	.083	.196	.640	

SUMMARY

Increased population growth and agricultural production will require substantial new water supplies in the near future. It is recommended that local governments exploring future water supply options to meet this projected demand, also investigate the option of desalination. This was mandated by the Florida Comprehensive Planning Act of 1984.

1. It is recommended that any local government desiring to use this technology have a pilot study on-site, testing different membranes before embarking upon a large scale plant.

2. It is also recommended that the feed water source be thoroughly tested as to its quality and quantity variability. Proper well construction is also recommended.

3. Monitoring wells to provide insight into the quality and quantity changes of feed water to RO plants should be installed.

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